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AN APPROACH TO THE PROBLEM OF
MEASURING SAFETY PERFORMANCE.

George Milt. Germanos

NAVAL POSTGRADUATE SCHOOL

Monterey, California



THESIS

AN APPROACH TO THE PROBLEM OF
MEASURING SAFETY PERFORMANCE

by

George Milt. Germanos

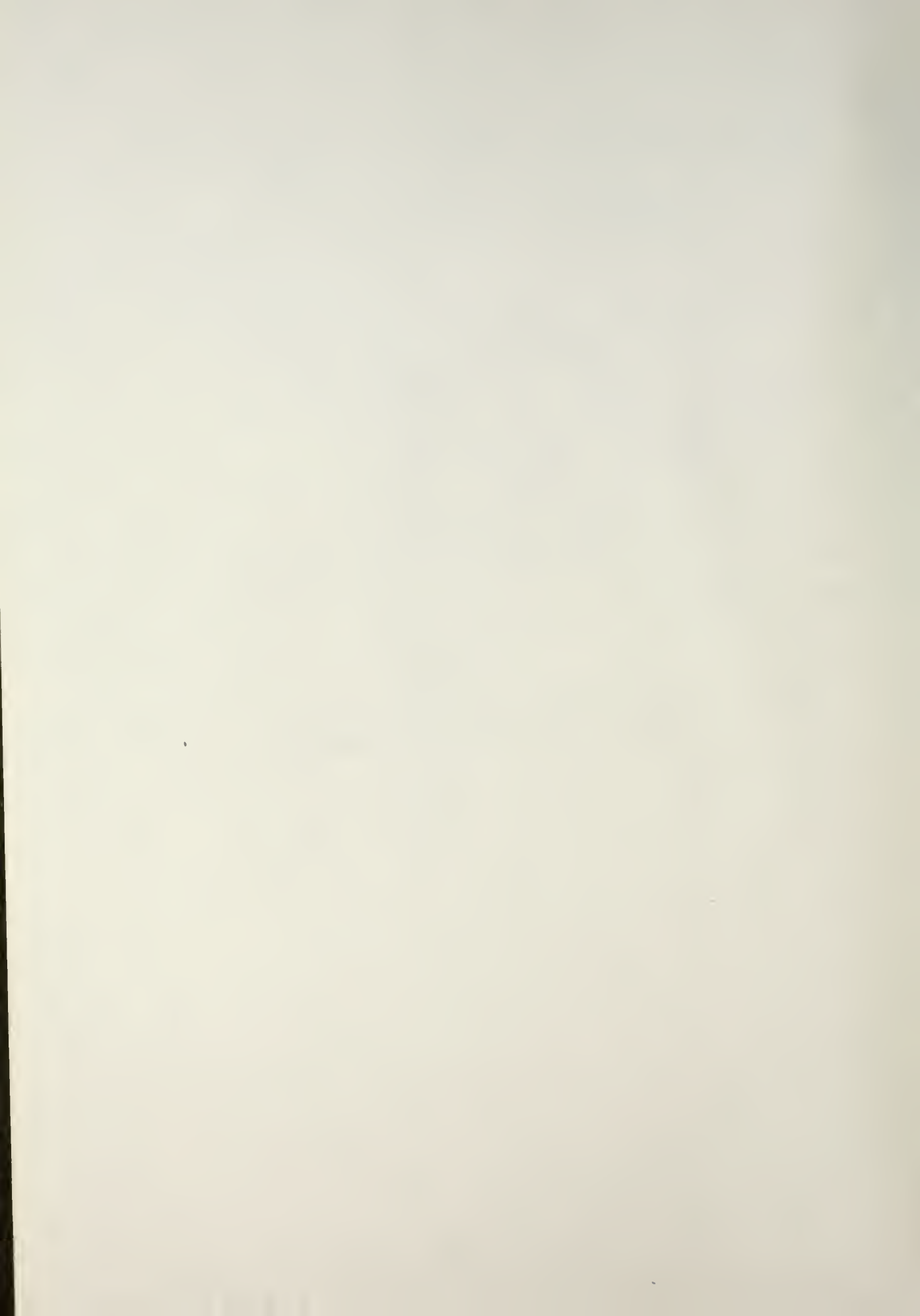
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An Approach to the Problem of
Measuring Safety Performance

by

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Lieutenant Commander, Hellenic Navy
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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

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ABSTRACT

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Having accomplished this survey a new methodology for measuring occupational safety performance is proposed based on "cost" criterion.

Finally an analysis of real safety occupational data is accomplished since analysis of safety data is considered to be a basic step of the proposed methodology.

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I. INTRODUCTION

Although safety is generally recognized as an essential part in overall system operation, incorporation of safety procedures and methodology is largely superficial and is usually directed at maintaining minimum legal standards at minimum cost. According to Lowrence (1976) safety is defined as a judgment of the acceptability of risk, and risk, in turn, as a measure of the probability and severity of harm to human health. Here it is proper to point out that since cost is incorporated in any severity of harm to human health, safety is a function of cost.

A function is safe if its risks are judged to be acceptable. This definition emphasizes the relativity and judgemental nature of the concept of safety. It also implies that two very different activities are required for determining how safe things are:

- a. Measuring risk, an objective but probabilistic pursuit.
- b. Judging the acceptability of that risk (judging safety), a matter of personal, social and economic value judgement.

Failure to appreciate how safety determinations resolve into the two discrete activities, is at the root of many misunderstandings. In one of the most common instances, it gives rise to the false expectation that scientists can measure

whether something is safe or not. They cannot, of course, because the methods of the physical and biological sciences can assess only the probabilities and consequences of events, not their value to people. Scientists are prepared principally to measure risks.

Since the taking of both personal and societal risks is inherent in human activity, there can be no hope of reducing all risks to zero. Rather, as when steering any course, we must continually adjust our heading so as to enjoy the greatest benefit at the lowest risk and cost.

Vital to any business function is an effective cost-control program - in safety, a program that allows for specific budgeting for injury cost and equally important, specific accountability for injuries. This method assumes that employee injury costs should be controlled just as any other production cost, since they increase operating overhead, as do the expenses for raw material, parts, and labor [Miller, 1977].

This is not a cold, inhuman approach to safety. There is a direct correlation between cost and human suffering. An accident that causes a great deal of pain and suffering will also generate high cost and loss of productivity. Thus, elimination of high-cost accidents will not only save money but also make the workplace safer and minimize the possibility of accidents that generate suffering [Miller, 1977].

Hammer (1972) in his Handbook of System and Product Safety has suggested that injury or damage can result from four fundamental causes or combinations thereof:

- a. material failure
- b. human error
- c. adverse characteristics of a product
- d. unusual environmental conditions.

Recently, personnel concerned with accident prevention have become more and more convinced that injury or damage from any of these causes can be prevented or lessened through good design and planning.

According to Zeller (1970) the interest in accident prevention or reduction has resulted in great public airing of the problem as well as increased awareness of the need for greater understanding of the causes if effective remedial action is to be developed.

There is, however, some confusion as to precisely what constitutes an accident. Review of accident statistics indicates vastly different criteria for accident reporting. For this reason, statistical comparisons and statistical analysis can be accepted only with reservation until there is assurance that the data sources are comparable. In the broadest definition any unexpected event might be considered an accident; for practical purposes, however, prevention is most applicable to those mishaps in which either damage or injury is sustained.

From the standpoint of cause and prevention, however, there is often little difference between circumstances that lead to destruction and those that result in only minor or no damage.

Another category of mishap - the hazardous condition or near miss - might also serve to alert personnel to incipient accidents.

It is axiomatic that effective prevention must have a focal point of application. This implies that the probable cause of future accidents can be predicted. This, in turn, implies that the causes of past accidents have been determined. In practice, the determination of the cause of an accident is no simple matter. It becomes increasingly apparent as any accidental occurrence is examined that there is seldom a single, clear-cut cause; more often there are multiple causes, which may be immediate or remote. Typical of this confusion is the accident involving the drinking driver who, while driving at excessive speed, leaves the roadway and crashes into some fixed object. It is very easy to attribute the cause of this accident to excessive speed, roadway conditions, fatigue, emotional instability, or to the social mores of a group that not only condones but encourages drinking and driving. This is quite compatible with the problem society faces when a crime is committed that, by careful analysis, can be laid directly at the doorstep of society itself. While this sociological evaluation of an accident or a crime may result in broad insight, it is not conducive to the practical determination of causation that can lead to relatively direct remedial action. For this reason, it is desirable to define cause so that all accidents can be evaluated within the same frame of reference [Lowrence, 1976].

One such definition defines the primary cause of an accident as the last act or event in a time sequence that made the accident inevitable from that point. While this, too, is subject to interpretation, it narrows the possibilities to a great extent. This kind of definition implies first a primary cause and, secondarily, contributing causes, with the primary cause by implication being the most important or, at least, the most proximate factor. This approach has the advantage of having one cause for each accident, which makes statistical manipulation simpler.

By contrast, other approaches list all causes without attempting to assign primacy to one, thus permitting the evaluation of all causes collectively without previously defined relative importance.

Unfortunately, even after critical evaluation has led to a determination of accident causes, the assessed cause may be a statement of what occurred rather than why it occurred. In the ultimate analysis of course, accident prevention must be based on why rather than what.

The most commonly designated cause of accidents is human error. In accidents where material failure is recognized, it is often quite possible to continue tearing down the equipment until the precise portion that failed is isolated and the cause of the failure whether it be corrosion, stress, faulty load conceptualization, or other factors, can be determined and redesign proposed. In cases of human error, however, the static statement that a human being failed provides no guidance

to future improvement. The need to reduce human error to its basic constituents as a means of obtaining insight into the causes of these failures has resulted in various approaches to segmenting human behavior for analytical purposes.

A more fruitful approach is to analyze human error in terms of a total man-machine system interaction in which a temporal continuum serves as the base line from which to evaluate the human contribution to the mishaps.

The major expense in a typical safety program is accident prevention. However, the general approach is to treat the symptom and not the cause of the accident on the basic premise that accidents are caused when employees create an unsafe act or condition. This superficial treatment of safety may arise from the fact that employers incorrectly and greatly underestimate the costs attributed to the industrial accidents and injury and also underestimate the role safety plays in the overall organization.

To put safety in its proper perspective, it must first be realized that safety and efficiency are products of each other. That is, the safe establishment is efficient. With this in mind, safety then becomes a management problem and not just the concern of the foreman or the supervisor.

There are five basic principles of a safety management program. These are:

- a. Accidents are suggestive of failures in the management system.

- b. Certain circumstances are predictive of severity of accidents.

c. Safety should be managed like any other operational function.

d. An effective safety program will provide establishment of responsibility and accountability.

e. An effective safety program will define situations that allow accidents to happen.

Now comes the problem of safety performance measurement. W. Tarrants (1977) discussed this problem as the problem that has existed since the very beginning of organized attempts to control accidents and their consequences. In its most elementary form, measurement has been defined as "The process of assigning numerals to objects according to rules" [Stevens, 1951]. When we apply this definition in the safety field, we are quickly confronted with problems concerning what "objects" to measure and what "rules" to follow.

As we learn more about the accident phenomenon we change our traditional concepts of describing it. Since measurement is primarily a descriptive process, we are in danger of believing that the description is the real thing and forgetting the nature of the phenomenon we want to describe. We tend to latch onto a particular type of measure and use it constantly which often prevents us from searching for and applying new measures which better describe the situation.

The progress and maturity of a science or technology are often judged by whatever success has been achieved in the use of measures. Measurement, perhaps more than any other single aspect, has been the principal stimulus of progress in all

professional fields. Measurement is the backbone of any scientific approach to problem definition and problem solution. Without adequate measurement in the safety field we cannot describe the safety state of our operations or determine whether or not our safety programs are really accomplishing anything. Sound measurement is an absolute prerequisite for control and both are necessary for prediction. As Tarrant (1977) suggests, accident control and prediction, valid and reliable measures of safety performance are essential in order to:

- a. Locate and describe problem areas,
- b. Identify causal relationships,
- c. Make decisions concerning the optimum allocation of accident prevention resources,
- d. Evaluate the effectiveness of applied countermeasures, and
- e. Detect when the system is deteriorating toward unacceptable limits of control.

The existing measures of safety performance some of which will be examined does not permit us to achieve these objectives at an acceptable level of effectiveness.

The purpose of this thesis research is to perform a literature survey of the various techniques by which safety program effectiveness is currently measured and to propose a methodology for the utilization of the recordable occupational injuries and illnesses data with an application based on the analysis of real data.

II. LITERATURE SURVEY

As suggested earlier, a safety program, like any organizational program must be measured, thus its effectiveness may be evaluated and its contribution to overall efficiency will be evident. Managers will compare, justify and make future predictions on the overall loss prevention strategy.

There are several methods in use of measuring safety performance effectiveness like frequency and severity rates, critical incident techniques, control charts, learning curves, safety sampling, Double Average Comparison Technique (DACOM), System Analysis Techniques etc.

A discussion of these methodologies is presented below.

A. FREQUENCY AND SEVERITY RATES

Frequency and severity as discussed by Simonds and Grimaldi (1963) are accepted standards by which a company can appraise its industrial injury record and set goals for achievement. Very roughly, these terms refer, respectively, to the relative frequency of occurrence of major injuries, on the one hand, and the total days lost, plus time charges for deaths and permanent impairments resulting from major injuries, on the other. It is important to be able to compare the injury record of one division with that of another in the same company, or of the company for the current year with its performance in preceding years, or of one company with other concerns in the same industry. For these reasons

and to facilitate the holding of contests among companies to stimulate accident-prevention efforts, the American Standards Association initially had established precise bases for computing frequency and severity rates (Z16.1 Code). In their calculations of safety performance based on rates, Simonds and Grimaldi have taken into account only disabling injuries. A single safety index developed by Western Electric was presented by Gilmore (1970) that is:

$$SSI = \frac{C \times 1,000,000}{16 \times D \times P}$$

where:

SSI = Single Safety Index

P = Number of plant personnel

D = Days in the period being measured

C = Charges as the total number of calendar days lost in excess of the first seven calendar days or 10 percent of Z16.1 schedule (whichever is greater) for both on-and off-the job injuries.

New concepts have been added to the disabling injury frequency method in this formula, first, there is a dependence on the severity of the accepted injury. Second, off and on the job disabling injury have the same weight. Third, the count on days charged begins with the eighth day of disability. Fourth, the use of 10 percent of the severity schedule for days lost under the Z16.1 code recognizes what some consider inequities within that schedule.

A test of a plant's performance by this index might serve to make managers more aware of the costs of manpower losses due to accidents.

1. Frequency Rate

The frequency rate is the number of disabling injuries as defined by the American Standard Association per million man hours worked. In mathematical terms it can be expressed as:

Frequency = Number of Disabling injuries ÷

$$\frac{\text{Number of manhours worked}}{1,000,000}$$

or for ease of computation,

$$\text{Frequency} = \frac{\text{Number of disabling injuries} \times 1,000,000}{\text{Number of man hours worked}}$$

Example 1. A shipyard concern employed an average of 2700 workers during 1978. Working 40 hours a week for about 50 weeks, each man put in about 2000 hours during the year. They experienced 65 lost-time injuries during the course of the period.

$$\text{Frequency} = \frac{65 \times 1,000,000}{2700 \times 2000} = 12.03 \text{ per million manhours}$$

A statement that the shipyard has a frequency rate of 12 means that 12 disabling injuries occur per million man-hours worked.

In calculating the number of disabling injuries, it should be noted that it is the number of disabling injuries and not the number of accidents that is intended for inclusion in the total. For example in a case of a catastrophic accident where 25 people were killed in an explosion, 25 disabling injuries would be included in the total number of disabling injuries for the unit's experience.

It is generally felt that frequency rates based on a million or more man-hours are very significant. Obviously, the smaller the sample, the less reliable is the rate as evidence of accident-prevention performance. Due purely to chance, the frequency rate of the shipyard in the above example might vary considerably from year to year. Nevertheless, the approximate yearly frequency rate would be a fairly good indication of how frequently activities got sufficiently out of control to result in serious injuries.

A frequency rate well over 12 could probably be reduced. In appraising this frequency rate, however, one should see how it compares with typical frequency rates in other firms doing the same type of job.

We know, as yet, nothing about how serious those 65 injuries were. That leads to consideration of a measure that will be affected by the seriousness of the disabling injuries.

The bureau of Labor Statistics uses a base of 100 full-time employees as opposed to the 1 million man-hours used by the American National Standards Institute (ANSI Standard Z16.1).

It is assumed that 100 full-time employees would work 200,000 hours per year (40 hours per week per worker, 50 weeks per year). Computed on this basis, the injury frequency rate for the shipyard mentioned would be:

$$\begin{aligned}\text{Injury frequency rate (BLS)} &= \frac{65 \times 200,000}{5,400,000} \\ &= 2.4 \text{ per } 200,000 \text{ man-hours.}\end{aligned}$$

2. Severity Rate

The severity rate is the number of days charged for disabling injuries per million man-hours worked. The time charges include, first, the number of actual calendar days (including holidays or plant shutdowns) on which the injured person was rendered unable to work in temporary total disability cases. Neither the day of the injury nor the day the injured worker returns to work is counted in the lost working days.

The method of computing severity as well as frequency rates are the Z16.1 - 1954 R. 1959 Publication of the American Standards Association (or American National Standards Institute ANSI). In Table I specific time charges are available which have been established by the American National Standards Institute for use for all other lost-time cases (deaths, permanent total, and permanent partial disabilities).

In this group of deaths and permanent impairments actual time lost from work in a particular case is not considered. The standardized time charges alone are applied.

Table I

The American Standard Scale of Time Charges

Nature of Injury	Time Charges as Number of Days Lost			
Death	6,000 days			
Permanent Total disability	6,000			
Loss of member or complete loss of use of:				
Arm above elbow	4,500			
Arm above wrist but not above elbow	3,600			
Hand above proximal joints of fingers, but not above wrist	3,000			
Thumb at or below distal joint	300			
Thumb above distal, but not above proximal joint	600			
Thumb metacarpal	900			
Other fingers:	Index	Middle	Ring	Little
Bone damage below distal joint	100	75	60	50
At or above distal but not including middle joint	200	150	120	100
At or above middle but not above proximal joint	400	300	240	200
Metacarpal loss	600	500	450	400
Leg above knee	4,500			
Leg at or below knee but above ankle	3,000			
Foot:				
At ankle	2,400			
Toes:				
Great toe at or below distal joint	150			
Great toe above distal but not above proximal joint	300			
Great toe meatarsal	600			
Any other toe:				
Distal phalange	35			
Middle phalange	75			
Proximal phalange	150			
Metatarsal	350			
One eye (loss of sight), whether or not there is sight in the other eye	1,800			
Both eyes (loss of sight), in one accident	6,000			
One ear (complete industrial loss of hearing), whether or not there is hearing in the other ear	600			
Both ears (complete industrial loss of hearing), in one accident	3,000			
Hernia (unrepaired)	50			
Note: If hernia is repaired, it is not counted as a permanent disability but rather as a temporary total disability				

Table I (Cont'd)

Finger tips: Loss of a finger tip without traumatic or surgical bone involvement is not give a standard charge but rather is treated like any temporary total disability.

The American Standard Scale of Time Charges

(taken from Simonds, R.H., and Grimaldi, J.V. [1963],
pg. 38)

For injuries involving more than one part of the body, the total may never exceed 6000 days. This was based on the life expectancy of the average worker times the number of working days per year. (The Bureau of Labor Statistics does not include a fixed charge for a fatality.)

With the Bureau of Labor Statistics method, only actual workdays lost are charged. The Bureau of Labor Statistics method requires time charges be included even if an employee is assigned another job; any change in occupation resulting from a work accident or illness is recordable. Therefore, by ANSI Z16.1

$$\text{Disabling injury severity rate} = \frac{\text{total days charged} \times 1,000,000}{\text{employees hours of exposure}}$$

Example 2. If in the previous example we had 20 disabling injuries in the shipyard resulting in 800 days lost, the disabling severity rate would be:

$$\begin{aligned} \text{Disabling injury severity rate} &= \frac{800 \times 1,000,000}{5,400,000} \\ &= 148 \text{ days per million man-hours} \end{aligned}$$

The average severity per injury can also be determined. This can be done in either of two ways:

$$\begin{aligned} \text{Average days charged} &= \frac{\text{Total days lost or charged}}{\text{Total number of disabling injuries}} \\ &= \frac{800}{20} = 40 \text{ (Average seriousness of injuries)} \end{aligned}$$

$$\begin{aligned}\text{Average days charged} &= \frac{\text{injury severity rate}}{\text{injury frequency rate}} \\ &= \frac{148}{3.7} = 40 \quad (\text{Average seriousness of injuries})\end{aligned}$$

Where injury frequency rate for the 20 disabling injuries in the shipyard is

$$\frac{20 \times 1,000,000}{5,400,000} = 3.7 \text{ per million man-hours}$$

In summary, both rates are needed in appraising safety performance, but the severity rate particularly should be examined over a several-year period. For comparison purposes the frequency rate is best, but since severity is actually a combination of the frequency and relative seriousness of injuries, perhaps a low severity rate is the most satisfying long-run accomplishment.

The evaluation of those rates is based on accident statistics, which, by their very nature, are collected after the fact. To be statistically valid, accident data must be collected either over long periods of time as already discussed or from a large number of similar activities. When they must be collected over a long period, by the time statistical validity has been established, operating conditions may have changed so that the data no longer apply.

Accident statistics provide valuable information to regulatory agencies and insurance companies. Regulatory agencies may use such data to identify causative factors and whether

additional safety requirements are needed to eliminate them in future accidents. Insurance companies can use accident data in determining costs of premiums, which are based on accident and injury frequencies and severity rates.

Unfortunately, even where accident and injury statistics can be useful, they are often incomplete, inaccurate, and therefore incorrect [Hammer, 1976].

Concluding the discussion about the frequency and severity rates as defined by the American National Standards Institute (ANSI), Standard Z16.1, as the number of disabling injuries sustained per million man hours worked for the frequency rate, and as the number of days charged to disabling injuries per million man hours worked for the severity rate, neither accounts for the magnitude and duration of the effect created by a change in the safety program.

Management therefore must wait until accidents occur before there can be a comparison to determine the effect a change has made in the safety program. This conclusion is supported by Duty (1970).

B. CRITICAL INCIDENT TECHNIQUE

The simplest way to find out from employees if they are aware of any hazards in their work environment is to ask them. The Critical Incident Technique is a means to do this most effectively. The method is based on collecting information on hazards, near misses, and unsafe conditions and practices from operationally experienced personnel. It can be used beneficially

to investigate man-machine operational relations and to use the information learned to improve equipment and operations. According to Hammer (1972) this technique consists of interviewing personnel regarding involvements in accidents; or near accidents, difficulties, errors, and mistakes in operation; and conditions that could cause mishaps. The surveys generally request the persons interviewed to include their own experiences and also experiences of other personnel whom they have actually observed. The person is asked to describe all near misses or critical mishaps that he can recall.

In effect the critical incident technique accomplishes the same result as an accident investigation: Identification through personal involvement of a hazard that has or could result in injury or damage. When the witnesses who observed a mishap or near miss, but were not participants, are added to those who were involved, an extremely large population is available from which information on possible accident cause can be derived.

Even isolated incidents reported by the technique can be investigated to determine whether corrective action is necessary or advantageous. However, when a large number of persons are interviewed regarding similar types of equipment or operations, similarities begin to appear in reports of hazards and near misses. Where these indicate deficiencies, difficulties, or other inadequacies, they can be accepted as indicators of areas in which improvements are necessary.

Attempts have also been made to produce similar effective results in obtaining information through the use of questionnaires to be filled in by selected personnel. This method has proved to be unsatisfactory for a number of reasons. One fundamental problem was the need for extreme care in selecting and phrasing the question. Too often, the person completing a questionnaire would give the questions interpretations neither considered nor intended by the person who prepared them. Any question should be avoided whose answer requires involved reasoning that is not immediately apparent to the reader.

The critical incident technique procedure is described by Tarrands as carried out at one plant of the Westinghouse Company. The steps are summarized by W. Hammer (1972) as follows:

a. A group of employees with previous experience and involvement in manufacturing processes and equipment was selected. Each person included was listed according to various factors, in order to produce as wide a range of experience as possible. Representatives were selected randomly from each factor group.

b. The participants were interviewed and informed of the study and its objectives. They were given an opportunity to withdraw from participation.

c. At the end of the interview the participant was given a copy of the statement on the study and its objectives and a list of typical incidents gathered at other plants. This procedure was to stimulate the recall process.

d. Participants were asked to describe any incident(s) that they could recall, whether or not they had resulted in injury or property damage. They were asked whether they recalled the incident similar to those that had occurred at other plants, as described on the list they had been provided.

e. Questioning was carried on until human errors or unsafe conditions in any recalled incident could be described.

Twenty participants related 389 incidents of 117 different types. Over 50 percent more potential accident causes were found by this method than had been identified from accident records. One participant estimated that almost 70 percent of the problems reported occurred every day, indicating an almost constant exposure to danger. According to Hammer (1972) the basis for the Critical Incident Technique is that it has been estimated that for every mishap there are at least 400 near misses and that for every serious injury that occurs, there are approximately 600 no loss accidents (incidents) that should serve as a warning to say that given enough time, it will occur. Once a potential accident has been reported, the hazards are corrected so that a real accident will not occur. As these hazards are eliminated or reduced so should accident frequency and severity rates.

The major deficiency of this method is that its effectiveness will be dependent upon all employees reporting those potential accidents (incidents) in which they are involved. Usually employees will be reluctant to do so. They are worried about their supervisors attitude, their own personal records

and/or spoiling the company's safety record. Thus data with some degree of bias are introduced.

C. CONTROL CHARTS

According to Brown (1976) a control chart is a visual means by which an analyst judges whether a process is in control or not. The measurements plotted on the chart are those of any random variable. Thus frequency and severity of accidents, as well as any other intermediate indicator of hazards, could be plotted. Judgements based upon these plots determine if the process is in control with respect to the random variable under consideration.

Figure 1 shows the typical layout of a control chart. The units of the random variable are given on the vertical scale, indicating that the height of the plotted point represents the value of the random variable for the indicated time period. The time scale, given horizontally, shows when the value occurred.

Although any one value can not be predicted, measurements of central tendency and spread define the expected concentration and range of the variable. Thus, if the variable behaves in a nonrandom way, we can conclude that an outside influence is affecting the random variable. The most common way of identifying when this occurs is through the use of an upper and a lower control limit. These are generally placed at equal distances above and below the mean line.

The measured values as they are recorded in time are plotted as indicated in figure 1. A point falling above or below the control limits, respectively, is indicative of an

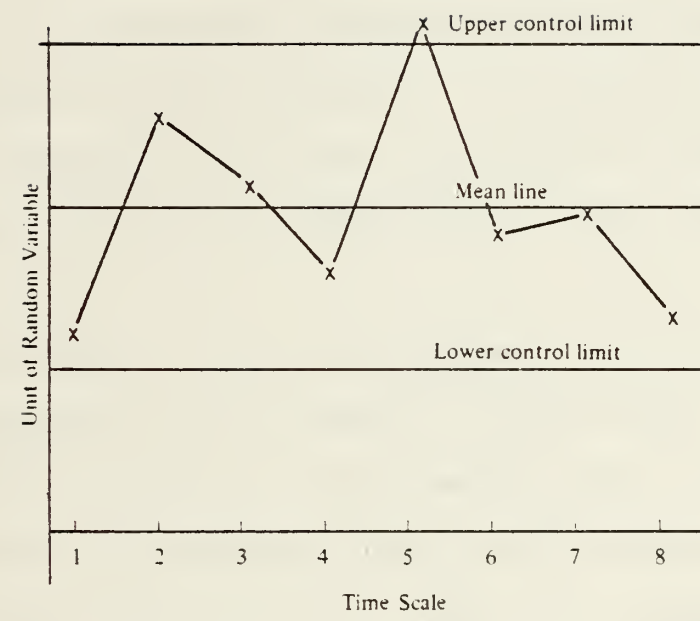


Figure 1: Example Control Chart

(Taken from Brown, D.B. [1976], Pg. 230)

out-of-control situation, and assignable causes are generally sought. There are other indications of out-of-control situations, also. However, prior to discussing these, the means for obtaining the control limits should be examined.

The procedures for setting control limits are essentially the same as those for setting the acceptance limits in a test of hypotheses. The first step involves the establishment of a level of significance (α), that is the probability of concluding that the process is out of control when in fact it is in control. If methods of identifying causes are expensive and the variable is not critical, a low probability can be tolerated. However, if an early indication of lack of control is necessary, then a high probability of this error should be specified.

Once the value of (α) is determined, the next question involves the definition of control. Quite often the state "out of control" occurs in one direction only. In sound-level readings, for example, rarely is the analyst concerned with the plant being too quiet. Here only an upper limit would be required, as it would in most cases of pollution measurements.

Other monitoring of processes would require both an upper and a lower control limit. In either case the value of (α) chosen will represent the total area of probability in the out-of-control portion of the chart. The upper and lower control limits are obtained depending upon the random variable, its distribution, and the value of (α) chosen.

Brown (1976) has suggested in the following example that the frequency of accidents, above a given severity for a plan, has a normal distribution with a mean of 6 and a standard deviation of 1.5. Frequencies for the first 6 months have been 4, 7, 5, 12, 8 and 6. In his example he allowed for a 0.05 probability of calling a point out of control when it is not. In this example a situation is said to be "out of control" when the random variable falls above the upper limit. However, the analyst chooses to set up a lower limit to provide possible evidence of a lowering of the accident frequency. Thus the 0.05 probability will be divided, 0.025 above the upper limit and 0.025 below the lower limit. The upper limit becomes: (using $z = \frac{x - \mu}{\sigma}$ which "standardize" any normally distributed random variable)

$$\begin{aligned}\text{Upper Limit (U.L.)} &= \bar{X} + z_{0.025}(\sigma_x) \\ &= 6 + 1.96(1.5) = 8.94\end{aligned}$$

where:

$$\bar{x} = \sum_{i=1}^n \frac{x_i}{n},$$

$$\sigma_x = \sqrt{\sigma_x^2}$$

$$\sigma_x^2 = E[(x - \mu_x)^2]$$

$$\mu_x = E[X]$$

and the lower limit also becomes:

$$\begin{aligned}\text{Lower Limit (L.L.)} &= \bar{x} - Z_{0.025}(\sigma_x) \\ &= 6 - 1.96(1.5) = 3.06\end{aligned}$$

The control chart is given in Figure 2. The fourth month was obviously out of control, and assignable causes should be sought. Any subsequent monthly reading that falls out of control should also prompt an investigation of the plant. In this example the assumption of normality should be tested since it does not hold generally. Rather than charting individual random variables, whose distributions may be unknown, often sample means are plotted. By the same procedure Accident-Severity Control charts may be obtained.

Thus any random variable can be plotted on a control chart. The construction of the chart is simply a matter of applying hypothesis testing on a continuous basis. The primary advantage is that continuous visual perception of the random variable is maintained.

This continuous picture enables the analyst to make judgments not otherwise discernible. This is not limited to the upper and lower control limits demonstrated above. Other factors that the analyst can use as indicators of abnormal operational behavior include:

- a. Several points (four or more) in a row on one side of the mean line. The probability of four consecutive points on one side is approximately 0.5^4 or 0.0625.

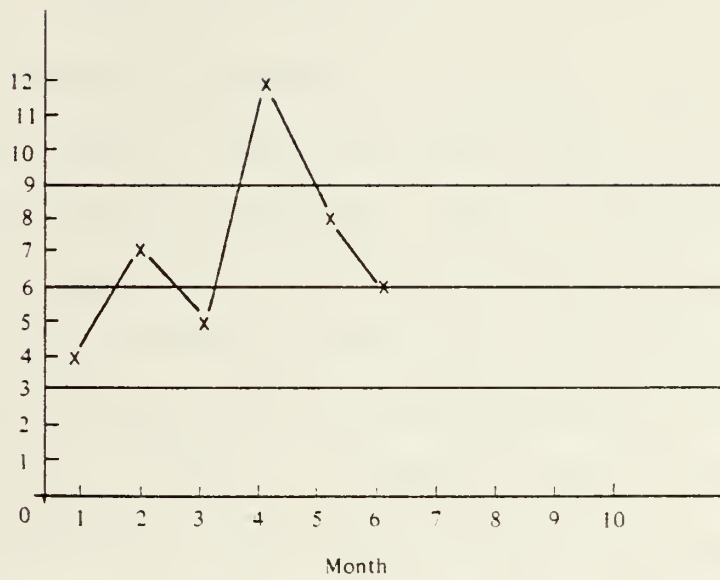


Figure 2: Control Chart

(Taken from Brown, D.B. [1976], pg. 231)

b. Identifiable cycles. Here two or three years of history may be required to identify a given month or other period of time when the operation acts in an irregular manner.

c. Several points in a row, either monotonically increasing or decreasing away from the mean line. The probability of this type of trend is difficult to establish. However, since these points are all on one side of the mean line the probability will be considerably less than 0.5^n , where n is the number of points exhibiting this characteristic.

In quality control situations, 3σ control limits are generally used, based on the 1-in-1,000 value of (α) under the normal-distribution assumption. The 2σ (accidents) and 1σ lines may also be set up, however, to help the analyst identify other out-of-control indicators. For example, two points in a row outside of 2σ limits would have an approximate probability of $(0.025)^2 = 0.000625$, which is about the same as the probability of one point outside 3σ limits, assuming normality. Although control charts for safety applications should not be restricted to the $\alpha = 0.001$ value, the concept of intermediate lines to identify irregularities is a good one.

Control charts are used in some states for monitoring traffic accidents. Overall accident frequencies, as well as finer breakdowns by severity classifications may be plotted.

However this technique also does not account for the magnitude and duration of the effect created by a change in the safety program. Therefore we must wait until accidents

occur before there can be a comparison to determine the effect a change has made in the safety program [Duty, 1970].

D. LEARNING CURVE

The learning curve method has been used extensively in production cost analysis. It was first developed by Dr. T.P. Wright for cost analysis of airplane production. He observed that the cost of producing each of a series of orders for airplanes of a particular model diminished as the orders were filled [Gilmore, 1970].

Experimental application of the learning curve has shown the effect of learning on the repetitive assemblies of equipment, the effect of incentives on productivity, the effect of low- and high-volume production, and other productivity situations. A logical use of this method would be to determine the obsolescence of manufacturing processes or the point at which cost improvement ceases unless a significant change is made in the process or that is replaced with a more modern, low-cost process.

In the study of the American petroleum industry an accident-experience learning curve model was developed, which closely corresponds to the conventional industrial learning curves.

As discussed by Gilmore (1970) we see that safe performance of work is also a learning process. Experience should teach us to do a better job of operating a massive crane to lift and place steel, or driving a truck etc. But people don't always learn. The job becomes routine and boring,

corners are cut, establishes procedures are violated, and accidents occur. Good safety programs appear so effective that change seems unnecessary, but even the effective ones can lose their punch. During orientation, workers are informed of the safety rules, but these are easily forgotten. Safety performance should improve as experience increases, programs improve in quality, job procedures are refined, and effort is applied. It seems logical that if production costs decrease as we learn how to produce more efficiently, safety performance should improve as we learn how to perform work more safely. Neither just happens; it takes a concerted effort on a continuous basis to make it so. The learning curve is just a method to chart the progress of that effort.

According to Dr. Wright the mathematical model for the learning curve is

$$Y_i = ai^{-b} \quad (1)$$

where

Y_i = The cost of the i^{th} unit,

a = The cost of the first unit; therefore $y = a$,

i = The production count beginning with the first unit,

b = The measure of the rate of reduction.

For the learning in safety performance if we represent the serious injury frequency by (SIF) and the total injury

frequency by (TIF) and using SIF as the measurement unit
equation (1) becomes

$$SIF_t = SIF_o t^{-b} \quad (2)$$

where:

SIF_t = the Serious Injury Frequency at time t .

SIF_o = the Serious Injury Frequency at the beginning of time.

t = the accumulated man-hours since beginning;
it can also be shown as million man-hours
or dated years on graph.

b = the measure of the rate of reduction.

As in the original learning equation (1), this model has the characteristic of describing constant percentage reductions. Each time (man-hour) increase of a constant percentage sees an accompanying injury frequency decrease of a constant percentage. If t_2 and t_1 are two points in the exposure history of a work group and $t_2 > t_1$, then

$$\frac{SIF_2}{SIF_1} = \frac{SIF_o t_2^{-b}}{SIF_o t_1^{-b}} = \left(\frac{t_2}{t_1}\right)^{-b} \quad (3)$$

The original safety equation (2) becomes

$$SIF_t = SIF_o \frac{1}{t^b} \quad t^b SIF_t = SIF_o$$

and by the log transformation we have

$$b \log t + \log \text{SIF}_t = \log \text{SIF}_0$$

or

$$\log \text{SIF}_t = \log \text{SIF}_0 - b \log t$$

which is the equation of a straight line with slope $-b$. The log transformation of the equation (3) is

$$\frac{\log \text{SIF}_2 - \log \text{SIF}_1}{\log t_2 - \log t_1} = -b = \text{the slope} \quad (4)$$

The learning curve can be constructed on a log-log graph paper on which SIF is plotted on the vertical ordinate and the accumulated man-hours on the horizontal ordinate. If the improvement in performance was steady, SIF values plotted would form a straight line of negative slope. This slope is the rate of learning or rate of improvement. These rates are expressed as a percentage of the no-improvement level of 100 percent. In other words, a learning rate of 80 percent is an improvement of 20 percent and has a slope equivalent to a reduction of 20 percent from the initial value or a new value of 80 percent of the initial value. This is shown on figure 3 where the 100 percent straight line is the no-improvement line. Those with the negative slope straight lines

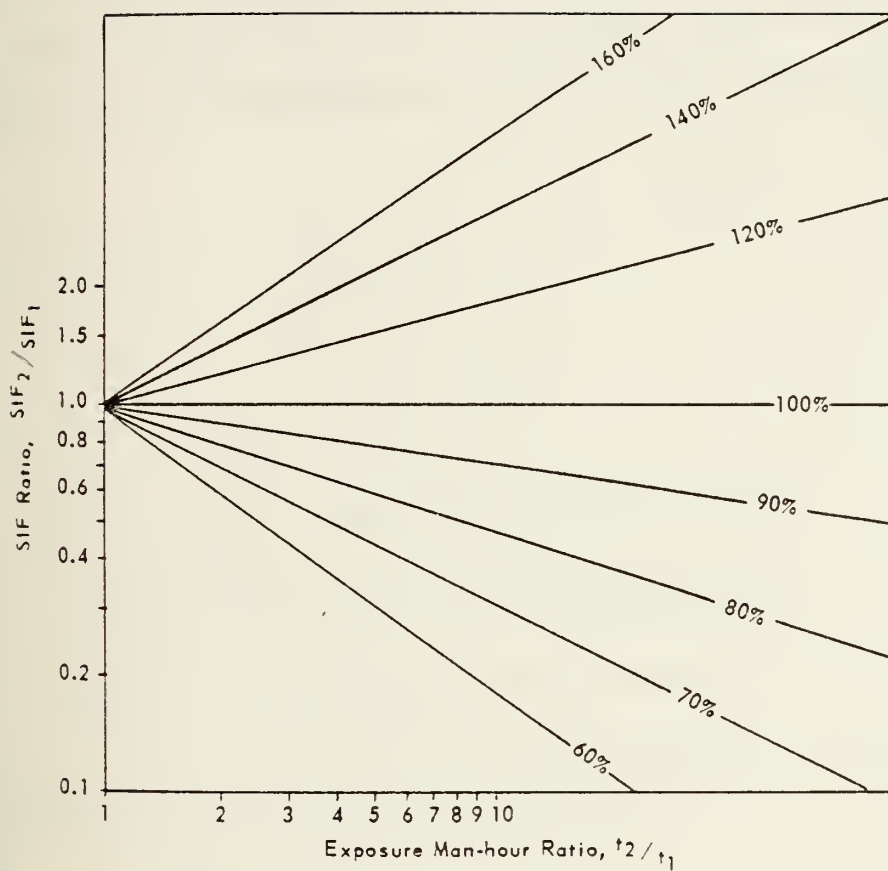


Figure 3: The Learning Rate Curve
 (Taken from Gilmore, C. [1970], pg. 93)

show the corresponding improvements of 10, 20, 30 and 40 percent respectively and those with the positive slope straight line show the corresponding negative improvement of 20, 40 and 60 percent respectively.

The rate of progress of the learning is usually described as that reduction of injury frequency (or whatever) which occurs when the time quantity is doubled. This then is equal to a quantity C^{-b} expressed as a percentage, where $\frac{t_2}{t_1} = C = 2$ then

$$C^{-b} = LR \quad (5)$$

where:

$$C = \frac{t_2}{t_1} = \text{the time ordinate ratio}$$

$$-b = \text{the slope of the plotted curve}$$

$$LR = \text{the learning rate expressed as a decimal.}$$

Making a log transformation and substituting the value $C = 2$

$$-b \log 2 = \log LR \quad (6)$$

and substituting (6) into (4) we obtain the equation

$$\log LR = \frac{(\log 2) (\log SIF_2 - \log SIF_1)}{(\log t_2 - \log t_1)} \quad (7)$$

This equation permits, by transposition, the calculation of reasonable expectations of injury frequency at some future time so that long and short-range goals can be set and performance charted against those goals as shown in figure 4. The equation for predicting or setting a goal in the future comes by solving (7) for $\log \text{SIF}_2$ and

$$\log \text{SIF}_2 = \frac{(\log \text{LR}) (\log t_2 - \log t_1)}{\log 2} + \log \text{SIF}_1 \quad (8)$$

Let us take, for example, a plant which accumulates two million man-hours each year. On January 1, 1978, the plant had accumulated 8 million man-hours and had an average SIF of 30 serious injuries per million man-hours for the last quarter of 1977. Point data for one month are quite variable, so at least three months of accident data are required.

By January 1, 1979, 2 million man-hours more have been accumulated, bringing the total to 10 million man-hours since operation began. SIF for the last quarter of 1978 was 27. What has been the learning performance rate?

Using equation (7)

$$\begin{aligned} \log \text{LR} &= \frac{(\log 2) (\log \text{SIF}_2 - \log \text{SIF}_1)}{(\log t_2 - \log t_1)} = \frac{(\log 2) (\log 27 - \log 30)}{\log 10 - \log 8} \\ &= \frac{(0.30103) (1.43136 - 1.477)}{(1.00000 - 0.90309)} = 0.14214 \end{aligned}$$

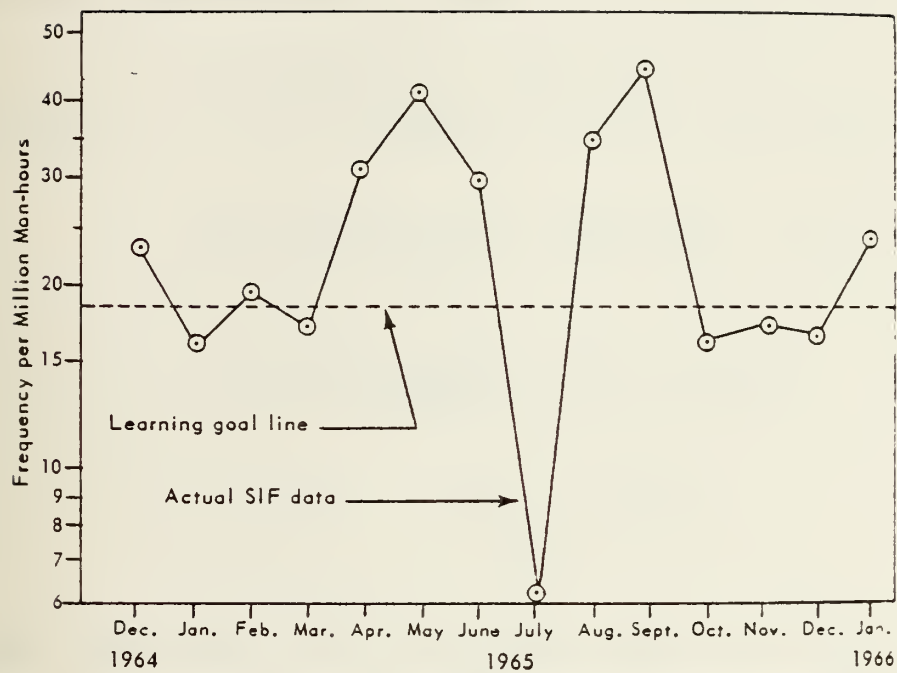


Figure 4: 1965 Safety Performance (based on serious injury data)
 (Taken from Gilmore, C. [1970], pg. 94)

and

$$LR = \text{Learning or performance rate} = 0.721 \text{ or } 72\%.$$

Assuming the goal for improvement was to continue through the coming year at the same rate, what is the goal for SIF at the end of 1979? Using the relationship (8) and assuming that two million man-hours will be worked by the same personnel during the coming year, we have

$$\begin{aligned}\log SIF_2 &= \frac{\log LR(\log t_2 - \log t_1)}{\log 2} + \log SIF_1 \\&= \frac{\log 0.721(\log 12 - \log 10)}{\log 2} + \log 27 \\&= \frac{-.14206(1.07918 - 1)}{0.30102} + 1.43136 \\&= 1.39399 \quad SIF_2 = 24.77.\end{aligned}$$

The same result ($SIF_2 = 24.77$) would have been obtained if SIF_1 of 30 at t_1 of 8 million man-hours had been used. Is this a good learning rate, or is improvement too slow? Any improvement is in the right direction. Studies generally agree that there is no universal curve that fits all learning. However, the learning curve provides the ability to recognize the existence or absence of progress and the desirability of measuring that progress. Improvement is important. When the learning curve flattens (100 percent) or goes up (greater than

100 percent), that plant or group has quit learning (improving) as already discussed and corrective action is in order.

Sociologists say that learning at the 80 to 90 percent rate is quite acceptable for a mix of men and machines. So a very reasonable goal for a safety performance improvement would be 10 percent per year.

A plot can be prepared to show this goal by using log-log graph paper and plotting SIF on the vertical ordinate and man-hours exposure along the horizontal. As time progresses, the actual values of SIF can be plotted to show their relation to the goal line. Due to the wide variations in monthly SIF values, the plotted points may not show any particular relationship to the goal line.

Thus the important aspect of this method is that it allows management to set goals for coming periods. But once again it does not account for the magnitude and duration of the effect created by a change in the safety program and we must wait until accidents occur before there can be a comparison to determine the effect a change has made in the safety program [Duty, 1970].

E. SAFETY SAMPLING

Another technique for the evaluation of safety performance is the safety sampling technique which according to Petersen (1971) is a method of systematically observing workers to determine what kind of unsafe acts are being involved as well as the frequency of occurrence of unsafe conditions. Using

those results we may come up with a safety performance figure.

There are some similarities between safety sampling and the critical incident technique. Duty (1970) has pointed out that safety sampling is similar to critical incident recall in that unsafe acts or conditions that might cause accidents are of interest. The difference is that this sampling is not directly coupled to the workers own initiative to report these conditions. Once the number of exposures is estimated through the sampling procedure, then is compared to previous figures and the number of exposures is studied. Fewer exposures means more effective safety program.

Gilmore (1970) presents the following examples concerning the use of safety sampling technique. Du Pont safety control program was examined. The number of unsafe acts and unsafe conditions found in a random selected sample of a work area, indicates a specific measure of the safety level in that area. This sample was made in each work area on a once-per-week schedule by a team of supervisors. The inspections were limited to 15 minutes. Inspection's time and team were randomly selected. Then a plot of the inspection results was performed to help in the interpretations. To ensure uniformity and competence of the samples, a training program for the supervisors had been established. The results were encouraging. It was found that an improvement in safety had occurred. This was a successful approach, in its primary purpose, of estimating the value of the safety level of individual sections as well as teams of

employees, within their sections and plants. The randomness of the inspection time had a positive effect since the plant was on a constant alert basis. Other companies such as Monsanto Company, Chrysler Corporation etc., have used this technique successfully. One procedure for safety sampling according to Petersen (1970) is:

1. Preparation of a Code: This is an element code list of unsafe practices that is developed from the accident record of each plant. Additional possible causes are listed. This code is placed on an observation form (see figure 5).

2. Sampling: The inspector will identify the department and the responsible supervisor. He then observes every employee, every activity of that area and records a safe or unsafe observation of the employee. Each employee is observed and is marked as safe or as unsafe if observed as performing safely or unsafely. Any unsafe practice is marked on the element code list. The accuracy required as well as the results of a preliminary survey will establish the number of observations within the sample.

3. Validation of the sample: From the preliminary survey suppose:

P = The percentage of unsafe observations

Y = Desired accuracy.

Then using the formula as suggested by Peterson (1970)

$$N = \frac{4(1 - p)}{Y^2(p)}$$

SAMPLING WORKSHEET Page <u>1</u> of <u>1</u> Safe observations Unsafe acts		DEPARTMENT													
		DC & Service	Maint power	Tool room	Foundry & pattern	Stock & shipping	Rotor	Shaft	Punch press	Body & frame	Bracket	Small winding	Large winding	Small assembly	11 q assem & pick
(1)	Improper lifting														
(2)	Carrying heavy load														
(3)	Incorrect gripping														
(4)	Lifting w/o protective wear														
(5)	Reaching to lift														
(6)	Lifting and turning														
(7)	Lifting and bending														
(8)	Improper grinding														
(9)	Improper pouring														
(10)	Swinging tool toward body														
(11)	Improper eye protection														
(12)	Improper foot wear														
(13)	Loose clothing--moving parts														
(14)	No hair net or cap														
(15)	Wearing rings														
(16)	Fingers/hands under dies														
(17)	Operating equip. at unsafe speeds														
(18)	Foot pedal unguarded														
(19)	Failure to use guard														
(20)	Guard adjusted improperly														
(21)	Climbing on machines														
(22)	Reaching into machine														
(23)	Standing in front of machine														
(24)	Leaning on running machines														
(25)	Not using push stick (fizz)														
(26)	Failure to use hand tools														
(27)	Walking under load														
(28)	Leaning--suspended load														
(29)	Improper use of compressed air														
(30)	Carrying by lead wires														
(31)	Table too crowded														
(32)	Hands and fingers between metal boxes														
(33)	Underground power tools														
(34)	Grinding on tool rest														
(35)	Careless Alum. splash														
(36)	One bracket in shaft piling														
(37)	Feet under carts or loads														
(38)	Pushing carts improperly														
(39)	Pulling carts improperly														
(40)	Hands or feet outside lift truck														
(41)	Loose material under foot														
(42)	Improper piling of material														
(43)	Unsafe loading of trucks														
(44)	Unsafe loading of skids														
(45)	Unsafe loading of racks														
(46)	Unsafe loading of conveyors														
(47)	Using defective equipment														
(48)	Using defective tools														
(49)	Evidence of horseplay														
(50)	Running in area														
(51)	Repair moving machines														
(52)	No lock-out on machine														
Total unsafe acts															
Additional unsafe acts															
(53)															
(54)															
(55)															
(56)															
(57)															
(58)															
(59)															
(60)															
(61)															
(62)															

Date _____ Time _____ Sampler _____

Figure 5: Safety Sampling Worksheet

(Taken from Petersen, D. [1971], pg. 76)

We may obtain the minimum number of observations (N) required for the validity of our results.

This method, as well as the others discussed so far does not account for the magnitude or the duration of the effect created by the safety program [Duty, 1970].

F. DOUBLE AVERAGE COMPARISON TECHNIQUE

Another method of measuring safety performance is the Double Average Comparison Technique method (DACOM) initially developed by Wilson (1970) of Sperry Flight systems to measure safety performance.

This method as briefly described below is based upon collection of number of exposures to potential accidents in various departments (or areas) of a company and compared with the number of man-hours worked during a certain period of time.

An achievement index is constructed based on reduction in number of exposures to potential accidents per million man-hours worked which gives an indication to the safety director if there is any improvement or not in various departments (or areas).

An interesting aspect of this method is that it may be utilized either with data collected by critical incident technique (or sampling method) or by the use of real accident data thus permitting management to compare departments in some uniform way and to have an indication of the effectiveness of a safety program before occurrence of accidents.

There is no indication whether this method may be economically utilized. The assumptions that should hold for the

method to be valid are:

1. A safety program exists,
2. This program had not changed over the period that this method is applied.

The following procedure is suggested by Duty (1970) for utilization of the DACOM method:

1. Collection of data for number of exposures to potential accidents in various locations of the company, using either the critical incident technique or better, by the safety sampling method.

2. According to the methodology described in the sampling technique section a code is prepared, sampling is conducted and calculation of the required number (N) of observations is determined.

3. The data of man hours worked in each area during each time period is obtained.

4. Achievement Index (AI) is defined as the reduction in number of exposures to potential accidents per million man-hours worked. This index is calculated for each period worked and is based upon short range improvement (SRI) and long range improvement (LRI). Assuming that the number of exposures to unsafe acts or conditions is a random variable normally distributed (for large number of exposures where the Central Limit Theorem holds).

5. The achievement index is then calculated for each group or area where data were collected.

A comparison between individual groups or between areas is feasible based on these achievement indices. This calculation of the (AI) is accomplished by $AI = a(SRI)_i + b(LRI)_i$ where AI is the Achievement Index for the i^{th} period with a and b the weighting constants based on the subjective management feeling for the importance of the Short and Long Range Improvements and $a + b = 1$ ($a = b = .5$ is an indication that the same importance is given to the short as well as to the long range improvements).

6. Calculations of the SRI and LRI necessary for the calculation of the AI is done by:

$$(SRI)_i = \frac{x_i - \mu_i}{\sigma_i}$$

where:

$(SRI)_i$ = Short range improvement of the group of workers for the i^{th} period.

X_i = Current performance for the i^{th} period which is the number of exposures per million man-hours worked.

μ_i = Historical mean performance of the group through the i^{th} period, and

σ_i = Standard deviation of the group through the i^{th} period.

For $i = 1$ that is the first period after the new program was initiated, the current performance (X_i) will equal the mean performance (μ_i) and $\sigma_i = 0$ since

$$\mu_i = \frac{1}{N} \sum_{i=1}^N x_i ,$$

$$\sigma_i = \sqrt{\frac{\sum_{i=1}^N (x_i - \mu_i)^2}{N-1}}$$

Also

$$(LRI)_i = (\mu_i - \bar{G}) / \sigma_{\mu_i}$$

where:

$(LRI)_i$ = Long Range Improvement for the larger group for the i^{th} group.

μ_i = mean performance of the smaller group and

σ_{μ_i} = the unbiased estimator of the standard deviation for the larger group.

\bar{G} = The group mean of the larger group,

\bar{G}, σ_{μ_i} are based on the total number of exposures to unsafe acts or conditions observed during each period for the entire company and

$$\bar{G} = \frac{1}{N} \sum_{i=1}^N G_i$$

where:

G_i = Current performance for the i^{th} period which is the number of exposures per million man-hours worked in the entire company,

N = number of periods, and

$$\sigma_{\mu_i} = \sqrt{\sum_{i=1}^N (G_i - \bar{G})^2 / N-1}$$

7. Interpretation and utilization of the Achievement Index as follows:

The smaller the achievement index the better, as a small number is indicative of a small number of exposures experienced by the group for which the AI was calculated. A negative AI is an indication that the group for which that AI was calculated did not exceed its mean, whereas the rest of the company experienced some exposures.

A regression line also may be formed to fit the AI of the previous years and the current one having the form:

$$\bar{y} = a + bx$$

where:

\bar{y} = The predicted value of achievement based on the data used,

x = The period number,

a = The intercept of the regression line = $\bar{y} - b\bar{x}$,

b = The slope of the regression line

$$= \frac{\sum_{i=1}^K (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^K (x_i - \bar{x})^2}$$

where:

x_i = The i^{th} period number,

\bar{x} = Mean of all periods,

y_i = Achievement index for the i^{th} period, and

\bar{y} = The mean achievement index for the overall periods.

Positive slope or more positive than the previous period can be interpreted as a rising tendency to more exposures.

Negative slope or more negative might indicate a falling tendency.

G. SYSTEMS ANALYSIS

In their article "The Economics of Safety ... A Review of the Literature and Perspective", I.R. Canada and M.A. Ayoub (1977) adopt the definition and description of systems analysis as given by E.G. Triner (1968) as follows:

Systems analysis is an inquiry to aid a decision maker to choose a course of action by systematically investigating his proper objectives; comparing quantitatively, where possible, the cost, effectiveness and risks associated with the alternative policies or strategies for achieving them, and formulating additional alternatives if those examined are found wanting.

Systems analysis is not only the comparison of alternative means of achieving a desired result but, more importantly, it is the vehicle for focusing attention upon the basic requirement itself. The means are complicated and are made up of a number of interrelated items. In systems analysis, the analysts, by varying the inputs, can assess the effects

upon both costs and output. Given a certain resource, the best combination of inputs may be determined to maximize output. Or, from a different point of view ... given the desired output, it can be determined how this output may be obtained at a minimum cost.

Safety analysts recognizing the needs for quantification developed several cost and performance models for analyzing the economics of safety problems. Roland (1975) has suggested a measure of safety performance which incorporates in a single parameter the essentials of that performance, that is the probability of the mishap and its severity. According to Roland (1975) when one first attempts to establish a decision methodology for safety analysis, the multidimensional nature of the criteria is immediately apparent. The traditional criterion of quantity of mishaps quickly breaks down when exposure variation is considered. Combining exposure with quantity of mishaps results in a rate. This rate is based on historical evidence and the extrapolation of this rate to future periods of time as a measure of satisfactory performance, can be accepted only under two limitations:

1. That the historical performance was typical or average.
2. That the system which generated the historical rate will not be substantially altered in the future period.

The matter of the level of historical performance may be satisfactorily resolved if there are multiple samples of the rate exhibiting stability.

For the variability of historical rate a suitable function of the chi-square distribution of the form

$$\lambda \leq \frac{x^2}{2T}; \quad 2F + 2$$

where:

λ = mishap rate

α = risk

F = number of mishaps (historical)

T = historical exposure,

is suggested by Roland (1975).

This function of the chi-square distribution will establish a conservative bound for a future criterion. Also this function assumes that the mishap rate varies as the chi-square distribution. Such a rate, usually single bounded, projected into future periods, can provide a measure of future performance given that no substantive alterations are made in the system.

Assuming an estimate of future exposure, the Binomial or Poisson distributions will determine the probability of future quantity of event occurrences.

$$\Pr(F = K) = \frac{(\lambda t)^k e^{-\lambda t}}{k!}$$

where

k = number of mishaps

t = future system exposure

The problem which arises from another dimension of the performance analysis, the severity of the mishap, given the probability of a future mishap and its value, the expected value may be formed as

$$E(C)K = \int_{-\infty}^{\infty} \text{Pr}(K)C(K)$$

where C = Cost

Certain probability functions will not allow this integral to be convergent. Such a case may be extremely costly for the user of such a system. Expected costs can be predicted in these cases by taking average values. It is frequently easier to perform a summation than to integrate the functions. Such a summation is given by

$$E(C)K = \sum_{n=1}^K \text{Pr}(n)C(n)$$

As another method of measuring safety effectiveness may be considered the method used by Brown (1976) who developed a Fault tree and cost/benefit analysis for choosing optimal

safety alternatives. J.R. Canada and M.A. Ayoub (1977)

summarize Brown's work as follows.

Brown shows how negative utility amounts can be assigned to all possible head events and the relevant probabilities multiplied by the negative utilities. The results, which are expected negative utility amounts, are called "measures of criticality" by Brown (1976).

Reductions in negative expected utility or criticality are considered to be quantitative expressions of benefits or effectiveness, and these are then related to costs to find the optimal combination of safety alternatives for the decision maker's cost-benefit trade-off function.

Using Brown's (1976) methodology the safety manager should first utilize the fault-tree analysis technique as a logical approach to identify the areas in a system that are most critical to safe operation.

Having developed the fault tree analysis the safety manager has an insight of the problem but for further quantification a quantitative analysis has to be accomplished so that effectively allocated the safety budget which is an upper bound for the actual decision to be taken.

Generally the best investments are those with the lowest cost/benefit figures, and these should be made first. Those figures may be interpreted as safety performance figures and when viewed in this perspective it becomes a powerful tool for improving the quality of safety investments.

Next the fault tree methodology will be examined since it is the basis for discussing Brown's approach to cost/benefit analysis. Following this discussion an application on cost/benefit analysis using fault tree analysis will be performed.

1. Fault Tree Analysis

Fault Tree Analysis, (FTA), was developed mainly by engineers who studied engineering systems in great detail, with little or no contribution by mathematicians. A possible explanation given by R.E. Barlow (1975); J.B. Fussell (1975) and N.D. Singpurwalla (1975) is the fact that the construction of the fault tree, a basic step in fault tree analysis, requires an intimate knowledge of the manner in which a system is designed and operated. The mathematician's lack of familiarity with the operation of systems, and perhaps their preoccupation with mathematically well defined problems, has deterred their interest in fault tree analysis.

According to R.E. Barlow (1975) and H.E. Lambert (1975), FTA is one of the principle methods of systems safety analysis. FTA evolved in the aerospace industry in the early 1960's. It was the result of a contract between the Air Force Ballistics systems division and Bell Telephone Laboratories for the study of inadvertant launch in the Minuteman ICBM [DeLong, 1970]. After initial work at Bell Telephone Laboratories, development of fault tree continued at the Boeing Company, where scientists devoted much effort to develop its procedures further and became its foremost proponents.

Rodgers (1971) has referred to the following six steps that were used in applying the technique to the

Minuteman Program.

1. Define the undesired event
2. Acquire complete understanding of the system.
3. Construct the logic diagram (Fault tree)
4. Collect quantitative data
5. Evaluate fault tree probability
6. Analyze computer results.

FTA is a detailed deductive analysis that usually requires considerable system information. It can be a valuable design tool. It can identify potential accidents in a system design and can help eliminate costly design changes and retrofits. FTA can also be a diagnostic tool. It can predict the most likely causes of system failure in the event of a system breakdown.

Undesired events requiring FTA are identified either by inductive analysis, such as a preliminary hazard analysis, or by intuition. These events are usually undesired system states that can occur as a result of subsystem functional faults. These events can be broad, all-encompassing events, such as "Release of Radioactivity from a Nuclear Power Plant" or "Inadvertent Launch of an ICBM Missile", or they can be specific events, such as "Failure to Insert Control Rods" or "Energizing Power Available on Ordnance Ignition Line".

The goal of fault tree construction is to model the system conditions that can result in the undesired event. Before the construction of a fault tree can proceed, the analyst must acquire a thorough understanding of the system.

In fact, a system description should be part of the analysis documentation. The analyst must carefully define the undesired event under consideration, called the 'Top or Head event'.

Practical considerations require that he scope the analysis, setting partial and temporal bounds on the system. To make his analysis understandable to others, the analyst should clearly show all the assumptions made in the construction of the fault tree and the system description used.

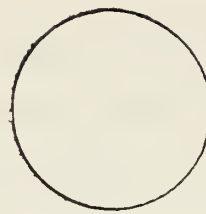
Event Description: A fault tree is a model that graphically and logically represents the various combinations of possible events, both fault and normal, occurring in a system that leads to the top event. The term, event, denotes a dynamic change of state that occurs to a system element. System elements include hardware, software, human and environmental factors.

Event Symbols: The symbols shown in figure 6 represent specific types of fault and normal events in FTA. The rectangle defines an event that is the output of a logic gate and is dependent on the type of logic gate and the inputs to the gate.

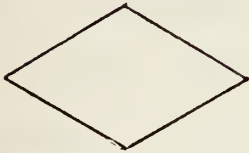
The circle defines a basic inherent failure of a system element when operated within its design specifications. It is therefore a primary failure, and is also referred to as a genetic failure. The diamond represents a failure other than a primary failure that is purposely not developed further. The switch event represents an event that is expected to occur or to never occur because of design and normal conditions, such as a phase change in a system.



Fault Event



Basic Event



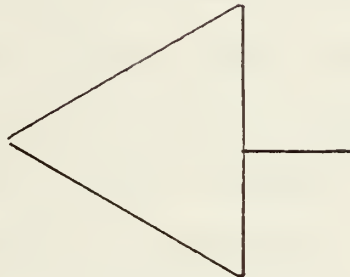
Undeveloped Event



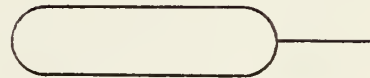
Switch Event



Transfer IN



Transfer OUT



Conditional Input

Figure 6: Event Symbols

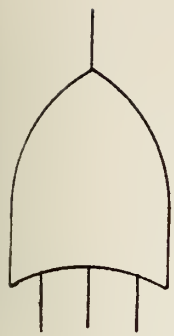
(Taken from Brown, D.B. [1976], pg. 158
and Rodgers, W.P. [1971], pg. 41)

Logic Gates: The fundamental logic gates for fault tree construction are the OR and the AND gates. The OR gate describes a situation where the output event will exist if one or more of the input events exist.

The AND gate describes the logical operation that requires the coexistence of all input events to produce the output event. Another gate used in the FTA is the inhibit gate. This gate permits applying a condition or restriction to the sequence. The input and condition or restriction must be satisfied for an output to be generated. The symbols for the logic gates are shown in figure 7.

Construction Methodology: The fault tree is so structured that the sequences of events that lead to the undesired event are shown below the top event and are logically related to the undesired event by logical gates. The input events to each logic gate that are also outputs of other logic gates at a lower level are shown as rectangles. These events are developed further until the sequences of events lead to basic causes of interest, called "basic events". The basic events appear as circles and diamonds on the bottom of the fault tree and represent the limit of resolution of the fault tree.

The structuring process used to develop fault flows in fault trees when a system is examined on a functional basis is presented in figure 8. At this level, schematics, piping diagrams, processes flow sheets, etc., are examined for cause and effect types of relationships to determine the



Output

Inputs

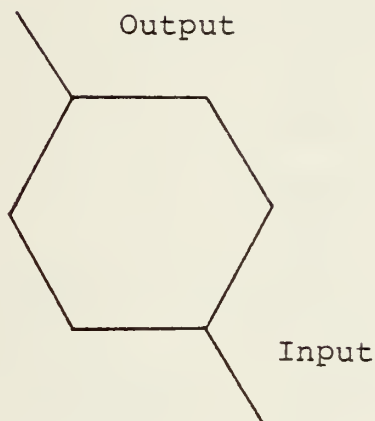
OR Gate



Output

Inputs

AND Gate



Output

Input

Inhibit Gate

Figure 7: Symbols For Logic Gates

(Taken from Rodgers, W.P. [1971], pg. 40)

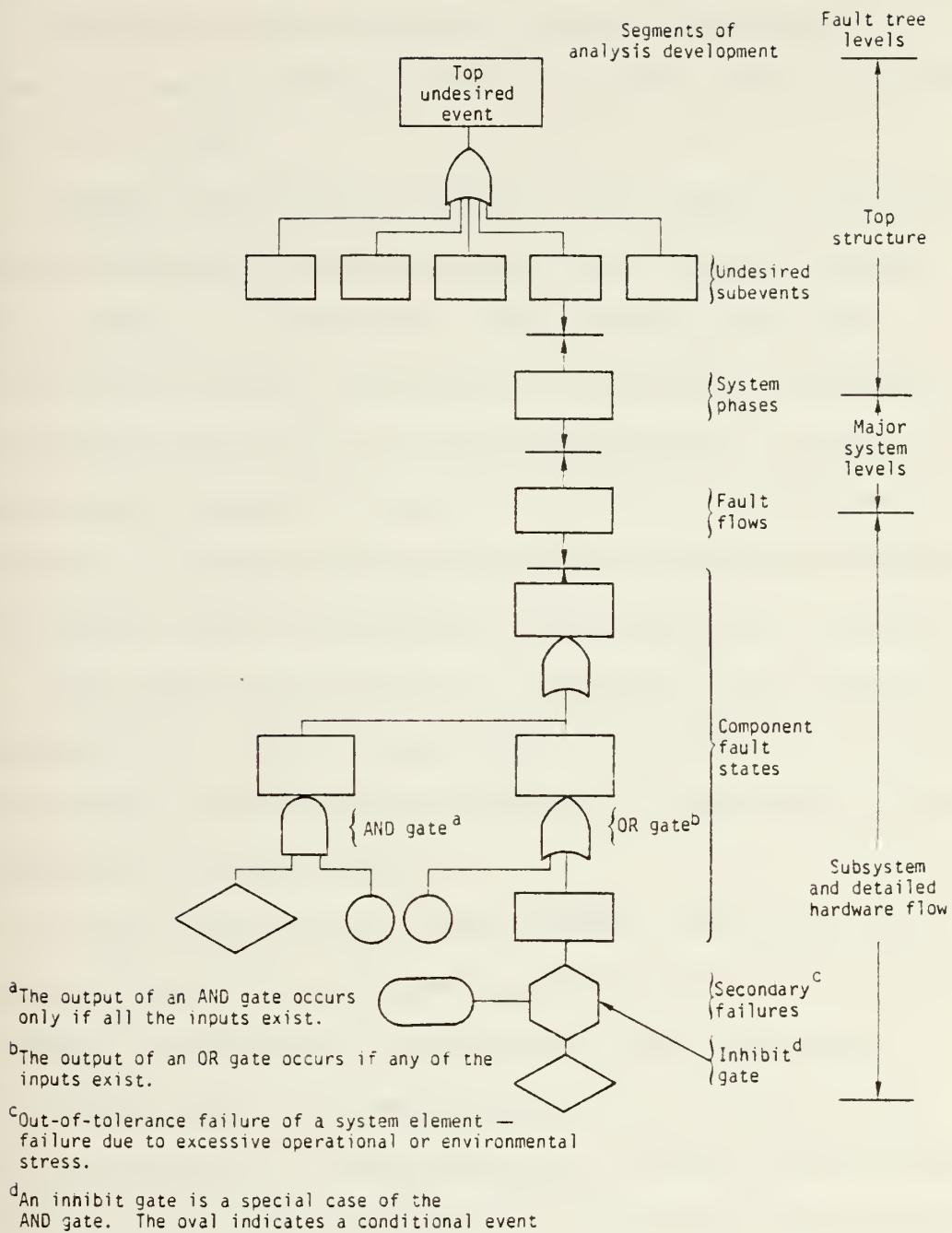


Figure 8: Levels Of Fault Tree Development

(Taken from Barlow, R.E. and Lambert, H.E. [1975], pg. 16)

subsystem and component fault states that can contribute to the occurrence of the undesired event.

Efforts have been directed toward automating fault tree construction for computer implementation [Fussell, 1972]; [Powers et al, 1975].

Purpose and Evaluation of the Fault Tree: The fault tree once constructed, serves as an aid in determining the possible causes of an accident. When properly used, the fault tree often leads to discovery of failure combinations which otherwise might not have been recognized as causes of the event under analysis. The fault tree can be used as a visual tool in communicating and supporting decisions based on the analysis, such as determining the adequacy of system design. The fault tree provides a convenient and efficient format helpful for either quantitative or qualitative evaluation of an event, such as determination of the probability of the occurrence of a top event.

In the fault tree and Cost/Benefit analysis as the major goal of the fault tree may be considered as the calculation of the probability of occurrence of the top event.

In many cases the construction of an initial fault tree may be reduced to a simplified one. There are basically two techniques for simplification of the boolean expression of a fault tree. That is either utilizing the Veitch diagrams or analytically utilizing the Boolean algebra identities. Appendix (A) gives these identities the familiarity of which increase the ability of manipulating Boolean equations.

According to Brown (1976) the purpose of developing a fault tree and quantifying it it to effectively allocate the safety budget. To do this, the various alternative safety investments are considered in light of their effect upon the fault tree and the resulting head event. A measure of cost/benefit is then determined for use in decision making. Before completing the presentation of Brown's methodology some terminology as given by Brown (1976) will be introduced.

Cost. Cost is defined as the dollar outlay to pay for the incorporation of a device, method, procedure and so on (henceforth called a countermeasure) into the industrial system for a given unit period of exposure. Thus the cost of devices that must be periodically recharged and/or replaced is based on average costs for a given unit (e.g., a 1,000,000 man-hour exposure period). Permanent fixtures, such as machine guards, can be prorated on the basis of the life of the machine. The cost of educational programs can be prorated, based upon their frequency. All countermeasures must, for comparison pruposes, have a common denominator.

Benefit. Benefit is the negative utility reduction. Measure of benefit is the expected negative utility. There is a negative utility (or cost in terms of dollars and personal well-being) associated with accidents. This negative utility depends upon the severity of the accident.

The expected negative utility of the head event if it occurs can now be calculated by the following:

$$E = \sum_{i=1}^n p_i u_i$$

where:

P_i = the probability of occurrence of the i^{th} severity class given that the head event occurs,

N = the number of severity classes,

u_i = the negative utility associated with the i^{th} severity class.

An alternative method for calculating E would be more appropriate if the values of negative utility from a large number of past occurrences of the head event were measured directly. Thus the expected negative utility associated with the head event would be obtained from the arithmetic mean of these measurements:

$$E = \frac{\sum_{i=1}^n u_i}{n}$$

Both equations are equivalent under the conditions that there are n severity classes ($N=n$) and that the probability of each severity class is equivalent ($P_i = \frac{1}{n}$). This occurs when each accident is considered as a unique situation.

Cost/Benefit: This term is a vague term used in describing a variety of applications. Here it is defined to be the dollars spent per negative utility reduction.

Absolute measure of "Criticality": Associated with

the head event is defined as

$$C = P \cdot E$$

where:

P = The head event probability of occurrence (in occurrence/mmh). (The technique for obtaining P will be discussed.)

E = The expected negative utility (in dollars/occurrence or workday/occurrence etc.). Thus the absolute criticality associated with the head event it takes into consideration both the frequency and the severity.

Determination of head-event Probabilities: The value

of P can be obtained assuming that a proper unit of time or production has been determined to adequately define one trial. Following directly the concepts of relative frequency and probability one way of determining P is

$$P = \frac{n_h}{n_u}$$

where:

n_h = the number of occurrences of the head event is n_u trials given by the chosen time or production time.

Another way of determining P is by using the fault tree end branch probabilities. This is necessary if the effect of alternative countermeasures is to be determined.

The probabilities of the branch events may be obtained as follows:

In the OR situation, any of the events will cause the subsequent event to occur and, therefore, assuming independence, the probability of occurrence of the subsequent event is given by

$$P_O = 1 - \prod_{i=1}^n (1 - q_i)$$

where:

q_i = the probability of the i^{th} causal event, and

n = the number of parallel branches.

In the AND situation, all the events must occur for the subsequent event to occur and, therefore, assuming independence, the probability of occurrence of the subsequent event is given by

$$P_A = \prod_{i=1}^n q_i$$

Through a reiterative process the probability of the head event can be determined from a knowledge of the probabilities of the branch events. This is the value of P that is used in determining the "criticality" associated with the

head event (or absolute expected negative utility). A system modification will produce a change in this value of the expected negative utility thus providing a measure of benefit which actually is a measure of safety performance.

Brown (1976) gives various examples to demonstrate the entire procedure. Here an example will be presented as a problem that has been formulated by Brown (1976) in his book Systems Analysis and Design for Safety. For the solution of this problem, Brown's methodology was followed as already described.

2. Example

It is desired to perform a cost/benefit analysis utilizing fault-tree analysis. The analysis will be performed on a stairway where the following accident data are assumed to be known, for a five years period. Slippery surfaces caused three accidents, inadequate railings caused five accidents, inattention caused two accidents, and obstacles on the steps caused one accident. If the negative utility for each accident was an average cost of 200 dollars and if 1000 dollars are to be spent for improving the safety of the stairway according to the following alternatives, each costs 500 dollars.

Alternative one. Install new surfaces, this will reduce the accidents caused by slippery surfaces by 70%.

Alternative two. Install new railings, this will reduce the accidents caused by inadequate railings by 50%.

Alternative three. Install warning signs and perform educational programs, by this alternative a reduction of

20% to the obstacle and railing-related accidents is expected.

Then perform the following:

- a. Construct a fault tree diagram for this example.
- b. Based on an evaluation of the alternatives the best allocation of the 1000 dollars should be determined.
- c. It is to be determined whether an alternative investment of 500 dollars in another area that would yield a cost/benefit of 50.00 be justified? (A 60-month denominator in calculating basic event probabilities will be used.)

3. Fault Tree Diagram Construction

For the construction of the fault tree diagram the following basic events are required.

- B. Person enters stairway with care
- C. Slippery surfaces of stair
- D. Inadequate railings
- E. Obstacles on steps
- F. Person enters stairway with no care (This basic event is the complement of B.)

From those basic events (or combinations), the head event accident on stairway (A) is likely to occur as follows:

Event B AND event C have caused 3 accidents in the past five years.

Event B AND event D have caused 5 accidents in the past five years.

Event B AND event E has caused 1 accident in the past five years.

Event F has caused 2 accidents in the past five years.

Thus events B AND C; OR events B AND D; OR events B AND E; OR event F is likely to produce the head event A. That is a stairway accident.

Figure 9 is the fault tree diagram that represents the above situations.

4. Basic Event Probabilities Calculations

A 60-month denominator will be used in calculating basic event probabilities since it is given so.

Event C

$$P_c = \frac{3}{60} = 0.05 \text{ Accidents/months}$$

Event D

$$P_d = \frac{5}{60} = 0.083 \text{ Accidents/months}$$

Event E

$$P_e = \frac{1}{60} = 0.0166 \text{ Accidents/months}$$

Event F

$$P_f = \frac{2}{60} = 0.033 \text{ Accidents/months.}$$

The probability of event B is assumed to be 1.

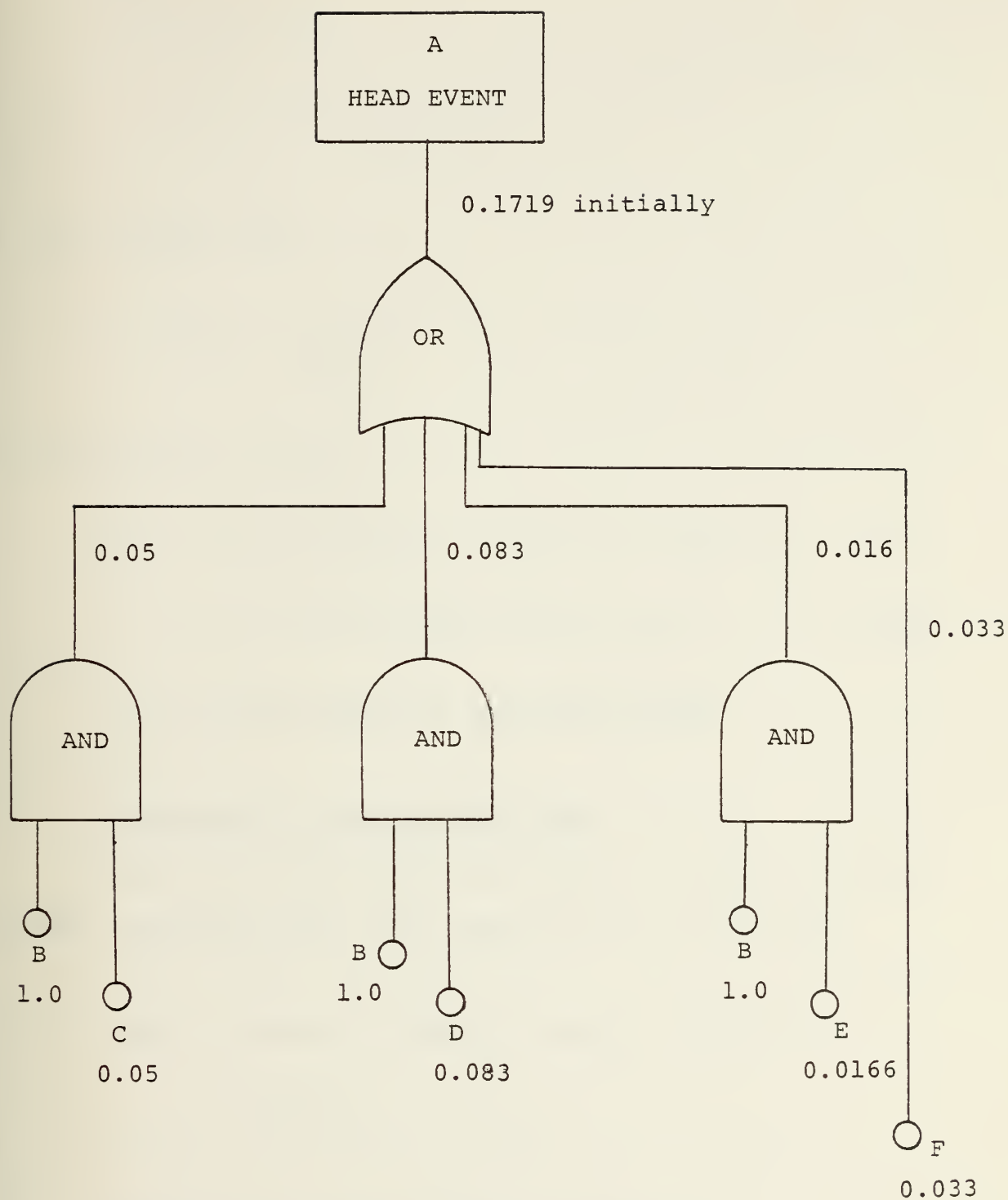


Figure 9: Example Fault Tree With Probabilities Assigned

EVALUATION OF THE HEAD PROBABILITY OF THE EVENT A

Using

$$P_O = 1 - \prod_{i=1}^n (1 - q_i)$$

for the OR gates, and

$$P_A = \prod_{i=1}^n q_i$$

for the AND gates we get

$$\begin{aligned} P &= 1 - (1 - 0.05)(1 - 0.083)(1 - 0.0166)(1 - 0.033) \\ &= 1 - (0.95)(0.917)(0.983)(0.067) = 1 - 0.828 \\ &= 0.1719 \text{ having an accident/months.} \end{aligned}$$

EVALUATION OF THE EXPECTED COST

Since it is given that the negative utility for each accident is \$200/Accident the expected cost is given by

$$\begin{aligned} E(C) &= 200(3) + 200(5) + 200(1) + 200(2) \\ &= \$2,200 \end{aligned}$$

EVALUATION OF THE ORIGINAL CRITICALITY

$$C = E(c) P, \text{ or}$$

$$C = (2,200)(0.1719) = 378.18$$

EVALUATION OF THE NEW CRITICALITY FOR ALTERNATIVES

ALTERNATIVE (1)

New surfaces which will reduce accidents caused by slippery surfaces by 70%. That is P_C reduces to

$$P_{C(1)} = P_C \times \frac{30}{100} = 0.05 \times \frac{3}{10} = 0.015$$

New head probability with alternative (1) is

$$\begin{aligned} P_{(1)} &= 1 - (1 - 0.015)(1 - 0.083)(1 - 0.0166)(1 - 0.033) \\ &= 1 - 0.985 \times 0.917 \times 0.983 \times 0.967 \\ &= 1 - 0.858 = 0.1414 \end{aligned}$$

New Criticality with alternative (1) is

$$C_{(1)} = 2,200 \times 0.1414 = 311.08$$

ALTERNATIVE (2)

New railings will reduce accidents caused by inadequate railings by 50%. That is with alternative (2) P_D reduces to

$$P_{D(2)} = P_D \times \frac{50}{100} = 0.083 \times \frac{1}{2} = 0.0415$$

New head probability with alternative (2) is

$$\begin{aligned}P_{(2)} &= 1 - (1 - 0.05)(1 - 0.0415)(1 - 0.0166)(1 - 0.033) \\&= 1 - (0.95)(0.958)(0.983)(0.967) \\&= 0.134\end{aligned}$$

New Criticality with alternative (2) is

$$C_2 = 2200 \times 0.134 = 294.8$$

ALTERNATIVE (3)

Signs and educational programs which are estimated to reduce railing-related accidents and obstacle related accidents both by 20%. That is with alternative (3) both P_D and P_E are reduced to

$$P_{D(3)} = P_D \times \frac{80}{100} = 0.083 \times \frac{4}{5} = 0.066$$

$$P_{E(3)} = P_E \times \frac{80}{100} = 0.0166 \times \frac{4}{5} = 0.013$$

The new head probability with alternative (3) is

$$\begin{aligned}P_{(3)} &= 1 - (1 - 0.05)(1 - 0.066)(1 - 0.013)(1 - 0.033) \\&= 1 - 0.95 \times 0.934 \times 0.987 \times 0.967 = 0.153\end{aligned}$$

The new criticality is

$$C_{(3)} = 2200 \times 0.153 = 336.6.$$

5. Summary of Alternatives

<u>ALTERNATIVE</u>	<u>COST</u>	<u>ORIGINAL CRITICALITY</u>	<u>NEW CRITICALITY</u>	<u>BENEFIT (savings)</u>	<u>COST/BENEFIT</u>
1	\$500	378.18	311.08	67.1	7.45
2	\$500	378.18	294.8	83.38	5.99
3	\$500	378.18	336.6	41.58	12.02

Since the constraint of the safety budget is \$1000 safety performance will better increase by choosing alternatives 2 (which is best in terms of cost/benefit) and 1 (second in terms of cost/benefit).

To answer the question "Would an alternative investment of \$500 in another area that would yield a cost/benefit of 50.00 be justified?", may be answered as follows:

$$\frac{\text{Cost}}{\text{Benefit}} = 50 \quad \text{since} \quad \text{Cost} = 500$$

$$\text{a benefit of } \frac{500}{50} = 10 \text{ should be found.}$$

Since ORIGINAL CRITICALITY - NEW CRITICALITY = BENEFIT, then 378.18 - NEW CRITICALITY = 10 and NEW CRITICALITY = 378.18 - 10 = 368.18 which may be achieved by varying one of the branch probabilities to give a head probability

$$P = \frac{368.18}{2200} = 0.167$$

III. STATEMENT OF THE PROBLEM

Already a variety of methods for evaluating safety performance have been discussed covering most of the existing techniques in use today.

From the above discussion it is apparent that this is an open area for research and development of new methodologies that will permit major improvement in overall safety systems. To support this some general area problems will be presented and limitations of the methods that already have been discussed will be considered.

The first main problem is that today there is not in existence either a unique methodology concerning safety evaluation or a unique measurement. That is, various methods exist and each one uses a different unit of measure. Some methods concentrate on rates, frequency or severity, others on indices, and others on cost or cost/benefit units.

Second, problems concerning most methods in use, is a lack of accepted minimum level of requirements. These requirements are varying depending on management policy, existing regulations, budget constraints, and controllable variables of the working environment.

Following is a brief overview of the literature survey methods discussed. The purpose is one of considering existing problems and limitations of these methodologies since those problems and limitations support the idea of the existing problem of safety performance measurement.

A. FREQUENCY AND SEVERITY RATES

The primary objective of this technique is to measure the injury experience of a corporation or its departments. Also we want to establish comparison criteria between departments or corporations for certain periods of time.

This comparison between companies creates a problem since most of the companies do not want to lose their reputation and biased data could influence results. In appraising safety performance, several-year periods are required so that the behavior of the safety program is better traced. The evaluation of those rates is based on accident statistics after the accidents have occurred, thus we are not able to predict the influence that a safety improvement might have on the safety performance. Finally those rates do not give any cost or lost-time indications. Thus these rates should not be used exclusively as the only means of evaluating safety performance.

B. CRITICAL INCIDENT TECHNIQUE

The main objective of this technique is to identify the effectiveness through personal involvement. That is its effectiveness is biased by the personal willingness to report a hazardous situation. Also it does not provide what the criteria are for measuring safety performance. Again we can not predict based on this technique for the amount of future improvement. For these reasons we may not adopt this as a primary method of measuring safety performance.

C. CONTROL CHARTS

Plotting on a chart frequency of accidents (number of accidents per million man hours or accident rates) vs. time to show comparisons between various departments or to give an overall picture of the safety program and to visually indicate out of control situations is the primary objective of this method. Again since we are plotting frequency rate the same restrictions that were examined for the frequency and severity rates hold here. Thus control charts should not be considered as the only accepted means for evaluating safety performance but rather might be used as indicators for presenting statistical data in graphical form.

D. LEARNING CURVE

A different approach to the problem of quantifying safety performance was presented by utilizing the information provided by the learning curve due to learning experience. Again here we can not rely on the learning effect for predicting future expectations of injury frequency at some future time since there are other factors that influence the positive improvements due to learning effect. That is, overestimating our ability or careless behavior should not be ignored. Also a change in the safety program can not be predicted by the learning curve.

E. SAFETY SAMPLING

This method may be considered as an improvement of the critical incident technique. That is it eliminates the bias

introduced by the workers and can be used as an excellent indicator concerning supervisory performance and motivation. Some problems that can be seen are the following:

In utilizing this method the most important act is that "of systematically observing workers in order to determine what unsafe acts are being committed and how often they are occurring". But the workers become more attentive when they realize that their unsafe acts are recorded.

Another problem is that this method does not account for the magnitude or duration created by improvements in the safety program.

F. DOUBLE AVERAGE COMPARISON TECHNIQUE

This method for measuring the effectiveness of a safety program has not been widely adopted. The following reasons might give some explanation. For collecting necessary data it is required to apply either the critical incident technique or the safety sampling methods. Thus, the problems already in existence with the utilization of these methods are introduced. The Achievement Index which is a function of the Short and Long range improvements depends on weighing constants that reflect "managements feelings as to the importance of Short and Long range improvements". This introduces a bias into the evaluation of the Achievement Index since it is the subjective feeling of management.

Finally it has been pointed out that strong assumptions should hold for correct implementation of this method. That

is, during the period of data collection (suppose a 3 or 4 years period) no change in the safety program has occurred.

G. SYSTEMS ANALYSIS METHODS

A wide range of approaches and techniques for analyzing the economics of the safety problems have been developed such as the systems analysis approach, fault tree and cost/benefit analysis approach, mathematical modeling approaches, etc. Those methods are using the concepts of utility or certain monetary equivalence (cost, losses, cost/benefit, etc.) as criteria for measuring safety performance effectiveness.

Since it was found that the most commonly used approach was the fault tree cost/benefit analysis approach, more emphasis has been given and an extensive presentation of its methodology has been provided. In this chapter some problem areas will be considered.

In many instances large amounts of time are required to understand the process, identify hazards, create the necessary fault trees and even then oversight and omission problems may arise. Since fault tree analysis (FTA) can be complex and time consuming, in many cases computers should be used to gather information, and construct and deduce the fault tree. However, again there are no clear cut programs to fit any specific case - thus the need for development of new programs might be necessary. Another problem in fault tree modeling is that it is difficult to apply Boolean logic to describe

failures of system components that can be partially successful in operation (i.e., a transmission system that might function, but not at a 100% level or leakage through a valve are two examples) and thereby have effects on the performance of the system. Another problem area is, that to apply the cost/benefit analysis quantitative evaluation of the fault tree is required. As a consequence in many cases we are faced with the problem to apply probabilities to the "man" since human failure or error cases is very difficult to be predicted and probabilities assigned.

As a last remark it should be pointed out that fault tree/cost-benefit analysis does not seem to be a proper methodology for evaluation of the overall performance of an organization but it is suggested for use in evaluating the effectiveness of specific areas, and particularly where there is an indication of potential hazard.

The review of various methodologies for measuring safety performance has indicated that further improvements in this area might be attained if additional effort was focused on cost related measures that will account not only for the effectiveness of existing safety programs but also for the effectiveness of those programs that continuously are modified to meet future requirements based on passed experience. The next chapter will concentrate on measuring occupational safety performance based on the above concept.

IV. AN APPROACH TO THE PROBLEM OF MEASURING SAFETY PERFORMANCE

Before trying to approach the problem of measuring safety performance two questions should be answered. These are:

- a. Why measure safety performance? And
- b. If measuring safety performance is a requirement, then what should be the measurement criterion?

It is not so difficult to answer the first question. There are many reasons dictating that measuring safety performance is a must. Measurement of safety performance provides a tool by which to judge its contribution in achieving the overall goals of an organization. Based on these measurements future predictions can be made. These measurements contribute mainly to control the current situation and predict the future.

The second question may be answered by choosing among the various criteria that already exist such as the "frequency criterion" or "severity" or "cost" or "lost man hours", etc. The most appropriate criterion chosen here is the "cost criterion". The reasons for choosing this criterion are the following:

- a. It is an easily understandable concept by management.
- b. It is appropriate in making comparisons among alternatives.
- c. It is an immediate indicator of the effective allocation of the safety budget.

d. Hidden costs become apparent and it becomes easier to trace whether we are moving within the bounds of the budgetary constraints.

e. The safety function as a positive contributor to overall organizational efficacy will be more appreciated.

After the criterion for measuring safety performance has been established an approach to the problem of measuring safety performance is possible.

This approach can be based upon seven main steps. These steps can be patterned after OSHA requirements and are as follows:

a. Preparation of the accident records according to Occupational Safety and Health Act (OSHA) requirements.

b. Coding of these data according to organizational structure to create an appropriate computer file.

c. Determination of the total (overall) safety related cost. This is a current measure of safety performance.

d. Determination of the average cost for each type of accident/incident.

e. Data analysis to develop a safety model. Based on this model future accident predictions can be made, provided that no significant changes in the safety program have been accomplished.

f. Computation of an expected total cost figure.

g. Cost/benefit analysis study of hazardous areas to identify alternatives to reduce the expected cost.

A detailed analysis to accomplish the above steps is given below.

Step (a). Preparation of the accident records. Preparation of the accident records is a very significant step since the overall approach is initially based on this recordable information.

The following records are required to be maintained by each employer with over seven employees according to OSHA.

a. Log of occupational injuries and illnesses OSHA form 100 or 100F modified (see figure 10).

b. Supplementary record of occupational injuries and illnesses, OSHA form 101 (see figure 11).

c. Summary-occupational injuries and illnesses, OSHA form 102 (see figure 12).

According to Showalter (1976) the log of recordable injuries and illness (form 100) should maintain all recordable occupational injuries and illnesses for that establishment. Each recordable occupational injury and illness should be entered into the log not later than 6 working days after the information about a recordable case has occurred.

Since this record is sufficient to provide all necessary information concerning the present methodology instructions for completing each column of this form, according to OSHA, are discussed below.

Column 1. Column 1 refers to Case or file number. Any number may be entered which will facilitate comparison with supplementary records.

Figure 10: Log of Occupational Injuries and Illnesses, Form OSHA - 100 (Taken from Petersen, D. [1975], pg. 19)

*Note: Column 9 is sometimes referred to as 9A, and 9B.

OSHA No. 101

Case or File No. _____

Form approved

OMB No. 44R 1453

Supplementary Record of Occupational Injuries and Illnesses

EMPLOYER

1. Name _____

2. Mail address _____
(No. and street) (City or town) (State)

3. Location, if different from mail address _____

INJURED OR ILL EMPLOYEE

4. Name _____ Social Security No. _____
(First name) (Middle name) (Last name)

5. Home address _____
(No. and street) (City or town) (State)

6. Age _____ 7. Sex: Male _____ Female _____
(Check one)

8. Occupation _____
(Enter regular job title, not the specific activity he was performing at time of injury.)

9. Department _____
(Enter name of department or division in which the injured person is regularly employed, even though he may have been temporarily working in another department at the time of injury.)

THE ACCIDENT OR EXPOSURE TO OCCUPATIONAL ILLNESS

10. Place of accident or exposure _____
(No. and street) (City or town) (State)

If accident or exposure occurred on employer's premises, give address of plant or establishment in which it occurred. Do not indicate department or division within the plant or establishment. If accident occurred outside employer's premises at an identifiable address, give that address. If it occurred on a public highway or at any other place which cannot be identified by number and street, please provide place references locating the place of injury as accurately as possible.

11. Was place of accident or exposure on employer's premises? _____ (Yes or No)

12. What was the employee doing when injured? _____
(Be specific. If he was using tools or equipment or handling material, name them and tell what he was doing with them.)

13. How did the accident occur? _____
(Describe fully the events which resulted in the injury or occupational illness. Tell what happened and how it happened. Name any objects or substances involved and tell how they were involved. Give full details on all factors which led or contributed to the accident. Use separate sheet for additional space.)

OCCUPATIONAL INJURY OR OCCUPATIONAL ILLNESS

14. Describe the injury or illness in detail and indicate the part of body affected. _____
(e.g., amputation of right index finger)

at second joint; fracture of ribs; lead poisoning; dermatitis of left hand, etc.)

15. Name the object or substance which directly injured the employee. (For example, the machine or thing he struck against or which struck him; the vapor or poison he inhaled or swallowed; the chemical or radiation which irritated his skin; or in cases of strains, hernias, etc., the thing he was lifting, pulling, etc.) _____

16. Date of injury or initial diagnosis of occupational illness _____
(Date)

17. Did employee die? _____ (Yes or No)

OTHER

18. Name and address of physician _____

19. If hospitalized, name and address of hospital _____

Date of report _____ Prepared by _____

Official position _____

Figure 11: Supplementary Record of Occupational Injuries and Illnesses, Form OSHA - 101

(Taken from Petersen, D. [1975], pg. 23)

Summary
Occupational Injuries and Illnesses

Establishment Name and Address

Injury and Illness Category		Fatalities	Lost Workday Cases			Nonfatal Cases Without Lost Workdays*	
Code 1	Category 2		Number of Cases	Number of Cases Involving Permanent Transfer to Another Job or Termination of Employment	Number of Lost Workdays	Number of Cases	Number of Cases Involving Transfer to Another Job or Termination of Employment
		3	4	5	6	7	8
10	Occupational Injuries						
	<i>Occupational Illnesses</i>						
21	Occupational Skin Diseases or Disorders						
22	Dust diseases of the lungs (pneumoconioses)						
23	Respiratory conditions due to toxic agents						
24	Poisoning (systemic effects of toxic materials)						
25	Disorders due to physical agents (other than toxic materials)						
26	Disorders due to repeated trauma						
29	All other occupational illnesses						
	Total—occupational illnesses (21-29)						
	Total—occupational injuries and illnesses						

*Nonfatal Cases Without Lost Workdays—Cases resulting in Medical treatment beyond first aid, diagnosis of occupational illness, loss of consciousness, restriction of work or motion, or transfer to another job (without lost workdays)

Figure 12: Annual Summary of Occupational Injuries and Illnesses, Form OSHA - 102

(Taken from Petersen, D. [1975], pg. 21)

Column 2. Column 2 refers to date of injury or illness.

For occupational injuries enter the date of the work accident which resulted in injury. For occupational illnesses enter the date of initial diagnosis of illness, or, if absence occurred before diagnosis, the first day of the absence in connection with which the case was diagnosed.

Column 3. Column 3 refers to Employee's name. First name or initial, middle initial, last name.

Column 4. Column 4 refers to the occupation. Enter the occupation title of the job to which the employee was assigned at the time of injury or illness.

In the absence of a formal occupational title, enter a brief description of the duties of the employee.

Column 5. Column refers to the department. Enter the name of the department to which employee was assigned at the time of injury or illness, whether or not employee was actually working in that department at the time. In the absence of normal department titles, enter a brief description of normal workplace to which employee is assigned.

Column 6. Column 6 refers to the nature of injury or illness and part(s) of body affected.

Enter a brief description of the injury or illness and indicate the part or parts of body affected. Where the entire body is affected, the entry "body" can be used.

Column 7. Column 7 refers to the injury or illness code. Enter the one code which most accurately describes the nature of injury or illness. A list of codes appears at the bottom

of the log. A more complete description of occupational injuries and illnesses appears below in "definitions".

Column 8. Column 8 refers to fatalities. If the occupational injury or illness resulted in death, enter date of death.

Column 9A. Column 9A refers to lost workday cases. Enter a check for each case which involves days away from work, or days of restricted work, activity, or both. Each lost workday case also requires an entry in column 9 or column 10, or both. Column 9A is not shown in figure 10.

Column 9B. Column 9B refers to lost workdays - days away from work. Enter the number of workdays (consecutive or not) on which the employee would have worked but could not because of occupational injury or illness. The number of lost workdays should not include the day of injury or onset of illness or any days on which the employee would not have worked even though able to work. Note: For employees not having a regularly scheduled shift, i.e., certain truck drivers, construction workers, part-time employees, etc., it may be necessary to estimate the number of lost workdays. Estimates of lost workdays shall be based on prior work history of the employee and days worked by employees, not ill or injured, working in the department and/or occupation of the ill or injured employee.

Column 10. Column 10 refers to lost workdays - days of restricted work activity. Enter the number of workdays (consecutive or not) on which because of injury or illness:

1. The employee was assigned to another job on a temporary basis.

2. The employee worked at a permanent job less than full time, or

3. The employee worked at a permanently assigned job but could not perform all duties normally connected with it.

The number of lost work days should not include the day of injury or onset of illness or any days on which the employee would not have worked even though able to work.

Column 11. Column 11 refers to non-fatal cases without lost workdays. Enter a check in column 11 for all cases of occupational injury or illness, which did not involve fatalities or lost workdays but did result in transfer to another job or termination of employment or medical treatment, other than first aid or diagnosis of occupational illness, or loss of consciousness.

Column 12. Column 12 refers to transfer to another job or termination of employment without lost workdays. If the check in column 11 represented a transfer to another job or termination of employment with no lost workdays, enter another check in column 12.

Some additional instructions for completing this log of occupational injuries and illnesses with definition of terms for use in recording occupational injuries and illnesses will be discussed for completeness of step one.

Initialing requirement. Each line entry regarding an occupational injury or illness must be initialed in the right

hand margin by the person responsible for the accuracy of the entry. Changes in an entry also must be initialed in the affected column.

Changes in extent of or outcome of injury or illness. If there is a change in an occupational injury or illness case which affects entries in columns 9, 10, 11 or 12, the first entry should be lined out and a new entry made. For example, if an injured employee at first required only medical treatment but later lost workdays, the check in column 11 should be lined out and the number of lost workdays entered in column 9. In another example, if an employee with an occupational illness lost workdays, returned to work, and then dies of the illness, the workdays noted in column 9 should be lined out and the date of death entered in column 8. An entry may be lined out if later found to be a nonoccupational injury or illness.

Definition of terms for use in recording occupational injuries and illnesses. Definition of terms for use in recording occupational injuries and illnesses are as follows:

Occupational injury. Occupational injury is any injury such as a cut, fracture, sprain, amputation, etc., which results from a work accident or from exposure in the work environment.

Occupational illness. Occupational illness of an employee is any abnormal condition or disorder, other than one resulting from an occupational injury, caused by exposure to environmental

factors associated with his employment. It includes acute and chronic illnesses or diseases which may be caused by inhalation, absorption, ingestion, or direct contact, and which can be included in the categories as listed below.

The listing that gives the categories of occupational illnesses and disorders that will be utilized for the purpose of classifying recordable illnesses can be seen in figure 10 under the term "illness codes". The identifying codes are those to be used in column 7 of the log.

Recordable occupational injuries and illnesses. Recordable occupational injuries and illnesses are any occupational injuries or illnesses which result in:

1. Fatalities, regardless of the time between the injury and death, or the length of the illness; or
2. Lost workdays cases, other than fatalities that result in lost workdays; or
3. Nonfatal cases without lost workdays, which result in transfer to another job or termination of employment, or require medical treatment, or involve loss of consciousness. This category also includes any diagnosed occupational illnesses which are reported to the Agency but are not classified as fatalities or lost workday cases.

Step (b). Coding of the accident data. Coding of the accident data according to organizational structure is a requirement for two main reasons that is, of storing the accident data in a computer for developing a "data bank",

and to be able to manipulate these data using a computer if necessary, to develop a safety model.

Coding depends on information required to be stored for future use. Suppose that the following information is necessary to be stored concerning each accident.

Year, month, day and day of the week that the accident occurred. This information may be taken from the accident log. The day of the week may be represented by one of the integers 1 to 7 indicating the corresponding days Sunday through Saturday.

Other information needed to be coded are the occupations and departments. Two integer numbers with sufficient number of digits depending on the size of the company may be used to code this information. That is, if in a company with 80 distinct occupations and 20 departments, two integer two digit codes are enough. Also the injury or illness code, number of deaths, lost workdays, and nonfatal cases without lost workdays as well as the cost of each accident may be coded and included in the computer file.

The next step is to determine the total safety related cost of each accident from which the overall safety related cost for a year will be determined.

In general the approach to this step is to evaluate the total cost of each accident as the sum of the two costs, direct and indirect, by following the detailed analysis as given below. The cost of each accident may be included in the data file as discussed above. Another cost that will

be calculated is the average cost for each type of occupational injury or illness as will be discussed later.

Step (c). Determination of the total costs. The total safety related costs of a company are composed of both fixed and variable costs in the following relationship.

$$\text{TOTAL COST} = \text{FIXED COST} + \text{VARIABLE COST}$$

The fixed cost term is the sum of three terms: F_1, F_2, F_3 where:

F_1 = The cost of safety related overhead,

F_2 = The cost required for compliance with government standards,

F_3 = The cost of elementary long term hazards.

The variable cost term is that cost associated with, and as a result of some type of accident. It is the sum of five different terms, each of which is the total cost of all accidents of a particular severity.

$$\text{VARIABLE COST} = \sum_{i=1}^n A_i + \sum_{i=1}^m B_i + \sum_{i=1}^j C_i + \sum_{i=1}^k D_i + \sum_{i=1}^l E_i$$

with:

$\sum_{i=1}^n A_i$ = The sum of A_1, A_2, \dots, A_n for the first,

second, third, etc., accidents of type A. severity. The same

holds for $\sum_{i=1}^m B_i$, $\sum_{i=1}^j C_i$, $\sum_{i=1}^k D_i$, $\sum_{i=1}^1 E_i$ where

$\sum_{i=1}^n A_i$ = Total cost of accidents where most severe injury resulted in a permanent total disability or death,

$\sum_{i=1}^m B_i$ = Total cost of accidents where most severe injury resulted in a temporary total disability requiring absence from work for more than one week,

$\sum_{i=1}^j C_i$ = Total cost of accidents where most severe injury resulted in absence from work for less than one week,

$\sum_{i=1}^k D_i$ = Total cost of accidents where most severe injury resulted in absence from work for less than one day,

$\sum_{i=1}^1 E_i$ = Total cost of accidents where there was no injury but material damage occurred or production was lost.

The total cost equation can be written with all its components as:

$$\text{TOTAL COST} = F_1 + F_2 + F_3 + \sum_{i=1}^n A_i + \sum_{i=1}^m B_i + \sum_{i=1}^j C_i + \sum_{i=1}^k D_i + \sum_{i=1}^1 E_i$$

where:

$n + m + j + k + 1$ = Total number of accidents over a year.

A series of data collection worksheets were developed to obtain accurate figures for input in the total cost equation. The first worksheet was designed to obtain the values associated with the fixed cost term of the equation. The second worksheet was an exhaustive survey of accident related costs for input into the variable term of the total cost equation (see figures 13 and 14, worksheets one and two).

So far a measurement technique of safety performance has been developed expressed as the overall safety related cost or "Total Cost" paid by a company in a year. Comparisons of this figure with previous years "Total Costs" enables the management to appreciate the effectiveness of the safety program and contribution of safety department to the company's goals.

To appraise the effectiveness of current safety programs an "Expected Total Cost" figure should be developed.

Step (d). Determination of the average cost for each type of accident. Determination of the average cost for each type of accident may be accomplished by utilizing the following logical approach. Based on the information collected using the worksheets discussed above, average cost for each type of accident A, B, C, D, and E may be computed as:

$$C_{A(AV)} = \text{Average cost for type A accident}$$

$$= \left(\frac{F_1 + F_2 + F_3}{n + m + j + k + 1} \right) + \frac{1}{n} \sum_{i=1}^n A_i$$

WORKSHEET ONE

DETERMINATION OF FIXED COSTS (ANNUAL BASIS)

$$\text{Fixed Cost} = F_1 + F_2 + F_3$$

I. F_1 : Overhead costs

A. Insurance Cost _____

(Future insurance cost can be estimated by projecting previous years insurance cost.)

B. Safety Department Salaries

1. Primary safety personnel safety

director's salary _____

Doctor's salary (if applicable) _____

Nurse's salary _____

Other primary safety personnel _____

2. Secondary safety personnel

Attendees at safety meeting _____

(Number of hours at meetings times
hourly wage plus travel expenses)

C. Percent Cost of company overhead for safety office (space and equipment) _____

D. Safety Department operating budget _____

E. Hiring cost incident to safety

(x-rays, medical/psychological exams) _____

G. In General other fixed expenses (Depending on the structure of the company) _____

Total F_1 Cost

\$ _____

Figure 13

II. F₂: GOVERNMENT COMPLIANCE COST

A. Safety Equipment _____

(If not included in safety department budget) include protective clothing, goggles, shoes, etc.; fire fighting equipment (purchase and maintenance)

B. Training

1. Cost of training personnel to comply with OSHA or other government standards (include manhour cost of instructors and employees plus training material) _____

2. Ongoing training (First aid, driver training, etc.; include manhour cost of instructor and trainee plus cost related to this training gas etc.) _____

3. Cost of drills (fire fighting etc., include manhour times plus all the related to the drill costs) _____

C. Cost to acquire or remodel equipment to meet OSHA or other, government standards _____

Total F₂ Costs

\$ _____

Figure 13 (Continued)

III. F_3 : Elementary Long Term Costs

A. Cost to eliminate long term occupational
or health hazards (if not included _____
previously), include research costs,
inspection and monitoring costs (manhours
times wages, etc.)

B. Cost related to environmental
protection measures _____

Total F_3 Cost

\$ _____

Total Fixed Cost ($F_1 + F_2 + F_3$)

\$ _____

Given that we have traced these fixed costs for previous
years we may easily predict the expected fixed cost of next
year based on these figures.

Figure 13 (Continued)

WORKSHEET TWO

DETERMINATION OF VARIABLE COSTS (FOR EACH ACCIDENT)

I. Type of Accident

A. Most severe injury resulted in permanent total disability or death. _____

B. Most severe injury resulted in temporary total disability or absence from work for more than one working week. _____

C. Most severe injury resulted in absence from work less than one week. _____

D. Most severe injury resulted in absence from work for less than one day. _____

E. No injury but material damage occurred or production time was lost _____

II. Wages lost

A. Lost time wages - personnel other than the injured workers

1. Non-injured workers who assisted the injured workers (hours off job times hourly wage) _____

2. Non-injured workers who stopped work to observe the happenings (hours lost times wages) _____

Figure 14

3. Non-injured workers who
stopped work due to machinery
shutdown or until replacement
was obtained for injured worker _____
- B. Lost time wages - injured personnel
 1. Lost time on job on day of
occurrence (hours times wages) _____
 2. Wages for subsequent days
absent from work. _____
 3. Wages for hours lost for
medical treatment after
returning to work _____
 4. Percent wages lost due to
decreased output after worker
returned to job. _____
- C. Lost time - Supervisors
 1. Lost salary/wages in direct
involvement with accident
(on scene assistance or
supervision) _____
 2. Salary/wages required for
filling out necessary
reports and forms _____
- D. Lost time - higher level management
(includes lawyer of the company)
 1. Direct involvement with accident
(salary rate times hours spent) _____
 2. Time devoted to follow-up function
(meetings, investigations, not including
fixed cost of safety department) _____

Figure 14 (Continued)

E. Start-up wages

1. Wages of personnel required to get plant back to normal operating speed _____
2. Overtime wages (if necessary) caused by getting plant back into normal operation _____
3. Wages of personnel brought in to clean up accident area _____
4. Wages of personnel brought in for non-productive observation/monitoring (securing guards, fire watches, observers to ensure pressure, temperature, etc., are maintained) _____

III. Production Lost

A. If lost production was recouped

1. Overtime wage rate differences to recoup lost production _____
2. Supervisors salary for overtime _____
3. Utility costs required for overtime _____

B. If lost production was not recouped

1. Value of goods lost _____
2. Cost to purchase goods or materials from other companies to continue with production or meet deadline _____

Figure 14 (Continued)

IV. Follow-up Costs

- A. Cost of OSHA fines _____
- B. Cost of production lost due to government shutdown _____
- C. Cost of obtaining replacement for injured worker (hiring cost and training costs) _____
- D. Production loss due to replacement worker operating below normal output _____
- E. Lost wages due to retraining other personnel in new or correct procedures as a result of accident. _____

V. Medical Cost (other than insurance)

- A. Doctor and hospital bills _____
- B. Costs of medical treatment _____
- C. Costs of prosthetic devices (wheel chair, etc.) _____
- D. Cost of altering work area to retain disabled worker _____
- E. Anticipated (estimated) increase in insurance rates as a result of accident (based on a loss experience modification factor) _____

VI. Equipment Cost

- A. Replacement or repair of damaged equipment _____
- B. Cost to redesign or build equipment (to remove/correct hazards) _____

Figure 14 (Continued)

C. Cost to rental equipment required
to continued production _____

VII. Off-Job Accidents

A. Wages lost due to absenteeism
because of off-job accidents _____

VIII. Other Costs

A. Lost profit on orders lost due
to accident _____

B. Loss of bonuses to company _____

C. Demurrage cost _____

D. Lost profit due to loss of reputation _____

E. Loss of profit due to labor strikes _____

TOTAL VARIABLE COST \$ _____

Figure 14 (Continued)

$C_{B(AV)}$ = Average cost for type B accident

$$= \left(\frac{F_1 + F_2 + F_3}{n + m + j + k + 1} \right) + \frac{1}{m} \sum_{i=1}^m B_i$$

$C_{C(AV)}$ = Average cost for type C accident

$$= \left(\frac{F_1 + F_2 + F_3}{n + m + j + k + 1} \right) + \frac{1}{j} \sum_{i=1}^j C_i$$

$C_{D(AV)}$ = Average cost for type D accident

$$= \left(\frac{F_1 + F_2 + F_3}{n + m + j + k + 1} \right) + \frac{1}{k} \sum_{i=1}^k D_i$$

$C_{E(AV)}$ = Average cost for type E accident

$$= \left(\frac{F_1 + F_2 + F_3}{n + m + j + k + 1} \right) + \frac{1}{1} \sum_{i=1}^1 E_i$$

Since those average costs are approximate figures for each type of accident a better approximation may be achieved utilizing the data of as many years as possible.

Step (e). Data analysis study. Data analysis study is a major step of this approach since by analysing the safety data information concerning accidents versus occupations or

departments or days of the week, etc., may be extracted. This will help to identify hazardous areas. Also the accident model may be developed. This model is likely to follow a "Poisson process" or might be a linear or non-linear regression model depending on the shape of the accident sample distribution. The development of the accident model enables the decision maker to make future predictions concerning the expected number of accidents. Thus, the computation of an expected cost figure which in the next step becomes feasible. The use of a computer might be a required tool for completion of the data analysis study.

Step (f). Computation of an expected total cost figure.

Computation of an expected total cost figure based on the information gained from steps d and e are as follows:

1. Having estimated an average cost figure for the various types of accidents and having developed an accident model the "Expected total cost" can be found as a function of the expected number of accidents and of the various average costs. This "Expected total cost" figure is a measure of future safety effectiveness since it indicates the expected total accident cost of next year, assuming that there are no changes in the safety program.

2. This figure can be improved by utilizing the cost/benefit analysis of the last step.

Step (g). Cost/benefit analysis. Cost/benefit analysis as discussed in Chapter II.G should be conducted for the most hazardous areas. This analysis will identify which alternatives

have the best cost/benefit figures. Adopting these alternatives a reduction in the number of the accidents should be expected. Thus a new expected number of accidents should be considered and a "New expected total cost" figure may be estimated.

This concludes the proposed methodology to the problem of measuring safety performance. It becomes apparent from the above discussion that it is not a clear cut methodology and a lot of work and time should be devoted to develop the various steps. The difficulties such as correctly completing cost worksheets; assigning probabilities to human beings and determining the potential for human error during the development of the cost/benefit step; developing the proper accident model, etc., will be faced and should be overcome.

But regardless of these difficulties this methodology is a logical approach to the problem of measuring safety performance.

The following chapter deals with the analysis of real occupational safety data of the civilian personnel of NPGS. The given data were collected as described in step (a) above. They were coded as per step (b) and were analyzed as per step (e). Finally some problem areas concerning the analysis of real safety data are discussed.

V. ANALYSIS OF REAL SAFETY DATA

The occupational injuries and illnesses data of the civilian personnel of the NPGS for a period of four years (1975-1978) were studied.

The purpose was to indicate with real safety data how the steps of coding and analyzing real safety data may be accomplished in a particular case. These steps with the cost/benefit analysis step as already discussed in Chapter II.A are major steps in the proposed methodology. Second, to appraise that today's needs require the safety manager to be supported by safety analyst personnel.

The data have been taken from the existing files in the NPGS "Log of Occupational Injuries and Illnesses" OSHA no 100 and 100F modified.

Coding of the data. The coding of the data was performed as follows. Three codes were developed, one for the days of the week as presented in table II, one for the occupations as presented in table III, and a last one for the departments as presented in table IV. The last two codes were based on the log information, thus it is likely not all the occupations nor all the departments are included. The coded information along with some additional information taken from the log were stored in a computer file, in the following structure.

Computer File FT01F001. This file contains the given accident data which have been sorted in ascending date order.

It was then observed that a small percentage (about 10%) of no cost accidents had occurred on the same day (ties). Since the tied accidents were accounted for only a small percentage of the overall five years data and since no one of those produce any total or partial workday loss they were eliminated. The file was structured as follows. Columns 1-3 refer to the date of the accident (year, month, day), column 4 designates the day of the week according to code I. Column 5 corresponds to the occupation based on code II. Column 6 corresponds to the department code III. Column 7 corresponds to the injury or illness code of OSHA, and columns 8, 9 correspond to the total or partial lost work days respectively.

Computer file FT02F001. The structure of the second file is just a one column four vector structure which represents the interarrival times in days between accidents, and is separated into four parts (vectors) each of which corresponds to one year period (1975-1978).

Analyzing the data. With the use of an IBM-360 computer the following work was completed.

1. Five tables were produced for: the 7 days; 12 months; 4 years; 72 occupations and 45 departments. In those tables information concerning the total number of accidents (TOT-AC), the type of accident (Types A, B, C for accidents that did not produce any work days lost, that produced partial days lost and that produced total days lost respectively), and

the total number (TL-DAY) and partial number (PL-DAY) of days lost are available.

2. Developed the following 5 charts for years, months, weeks, occupations and departments vs total number of accidents, total and partial days lost.

3. Histograms of the interarrival (or interevents) times of the accidents were developed for each year and each week in order to gain an understanding of whether the accidents were following any particular distribution pattern. For some weeks, where the sample sizes was too small, that is less than 10 accidents, it was not possible to get a histogram. With the histograms all the information concerning central tendency, spread, higher central moments were available.

4. Having developed the histograms it was reasonable to assume that the distribution of the interarrival times of each year were following an exponential distribution with means $\mu_1 = 6.471$, $\mu_2 = 4.329$, $\mu_3 = 5.166$, and $\mu_4 = 5.185$ for the accidents of the years 1975 through 1978 respectively. For verification of the above a Kolmogorov-Smirnov test was performed by means of the NKS1 existing library subroutine.

Results. Results based on the above work were as follows: From the developed tables and charts more accidents occur on Fridays and less on Sundays and Saturdays but more or less the number of accidents is evenly spread during the week days Monday to Fridays.

Concerning the months, January and December are the months with lowest frequency of accidents where February and November are those with the greatest frequency. But again more or less the accidents are evenly spread during all months. Concerning occupations those with the largest number of accidents are the clerks, laborers, pipefitters, gardeners and food service employees. A total number of 409 work-days lost and 28 partial-days lost occurred.

Concerning departments those with the largest number of accidents were the Public Works, Naval Exchange, COMO and supply departments.

Cost Analysis. A cost analysis was performed based on rough cost figures given by the safety department of the NPGS. Those figures were an average direct cost of 8.38 dollars/hour for every occupation and the amount of 300 dollars for a "back case" injury which roughly speaking represents the medical bills.

Based on the above given figures it was not possible to determine a total cost figure as discussed in Chapter IV and only a rough total cost estimate was evaluated as follows.

Daily average direct cost figure = Average hourly cost x
8 hrs = $8.38 \times 8 = 67.04$ dollars/day lost.

Since there were

409 total days lost x 67.04 dollars/day lost

= 27,419.36 dollars, and

since there were

$$28 \text{ partial days lost} \times \left(\frac{67.04}{2}\right) \text{ dollars/half day} = 938.56.$$

Thus rough average total direct cost = $27,419.36 + 938.56$
= 28,357.92 dollars.

A 4 year Accident Model of the NPGS (from 1975-1978).

According to Ross (1970) a stochastic process $\{N(t), t \geq 0\}$ is said to be a counting process if $N(t)$ represents the total number of events which have occurred up to time t . A particularly important counting process is the Poisson process defined as follows:

The counting process $\{N(t), t \geq 0\}$ is said to be a Poisson process if

- (a) $N(0) = 0$
- (b) $\{N(t), t \geq 0\}$ has independent increments. That is the number of events which occur in disjoint time intervals are independent
- (c) The number of events in any interval of length t is Poisson distributed with mean λt . That is, for all $s, t \geq 0$

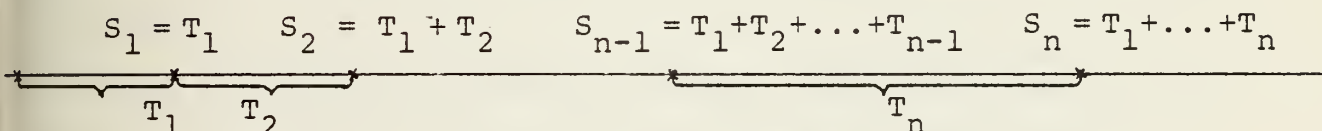
$$\Pr\{N(t+s) - N(s) = n\} = e^{-\lambda t} \frac{(\lambda t)^n}{n!}, \quad n = 0, 1, \dots$$

From condition (c) it follows that a Poisson process has stationary increments, that is the distribution of the numbers

of events which occur in any interval of time depends only on the length of the time interval, and also that $E[N(t)] = \lambda t$ and λ is called the rate of the process.

The following theorems concerning the Poisson process are essential for the establishment of the accident model.

Theorem 1. If $\{N(t), t \geq 0\}$ is a Poisson process then the inter-arrival (or inter-event) times $\{T_i, i \geq 0\}$ are independent identically distributed exponential (λ)



Corollary 1. If $\{N_t, t \geq 0\}$ is a Poisson process then the waiting times $\{S_n = T_1 + \dots + T_n, n \geq 1\}$ are Gamma distributed with parameters n and λ .

Theorem 2. If the inter-event times $\{T_i, i \geq 1\}$ of a counting process $\{N_t, t \geq 0\}$ are independent identically distributed Exponential (λ) then $\{N(t), t \geq 0\}$ is a Poisson process with rate λ .

To develop the accident model of the NPGS it was assumed that $N(t)$ = the number of accidents which have occurred at NPGS at or prior to time t , where the time t is measured in days.

If $T_1, T_2 - T_1, T_3 - T_2, \dots$ represent the interarrival (or inter-event) times of the first, second, third, ... accidents

then those interarrival times are independent and identically distributed. Examining these interarrival times for each year separately and having performed the appropriate Kolmogorov-Smirnov tests (see summary of results in table V) we accept the hypothesis that the interarrival times are independent and identically distributed random variables each with an exponential distribution with mean $\mu_1 = 6.4716$, $\mu_2 = 4.329$, $\mu_3 = 5.166$, $\mu_4 = 5.185$ ($\lambda_1 = 0.15$) ($\lambda_2 = 0.22$) ($\lambda_3 = 0.19$) ($\lambda_4 = 0.19$), where μ_i , λ_i are the mean and parameter of the exponential distribution of the data of the i^{th} year.

Thus according to theorem 2 above, each year from 1975 to 1978 the occupational injuries and illnesses models were following a Poisson process, with rates

$$\lambda_1 = 0.15 \text{ accidents/day for 1975}$$

$$\lambda_2 = 0.22 \text{ accidents/day for 1976}$$

$$\lambda_3 = 0.19 \text{ accidents/day for 1977}$$

$$\lambda_4 = 0.19 \text{ accidents/day for 1978}$$

Based on these findings we may consider that the 1979 accident model is likely to follow a Poisson process with rate

$$\lambda = \frac{\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4}{4} = \frac{.75}{4} = 0.187 \left(\frac{\text{accidents}}{\text{day}} \right)$$

Computer Programs. Basically three computer programs were developed named as B, DS, and C. Program B was developed to calculate the interarrival times of the accidents. Program DS was developed to produce the necessary tables and plots as already discussed. Program C was developed to produce histograms and perform Kolmogorov-Smirnov tests as discussed.

Discussion and conclusions. Having analyzed a four year accident data of the civilian personnel of NPGS it was found that the 1975 accident model was following a Poisson process with rate $\lambda = 0.15$. This was based on a Kolmogorov-test where at a level of significance $\alpha = 0.10$ the accident inter-arrival times were accepted to be exponentially distributed ($\lambda = 0.15$), thus the process as already discussed was Poisson.

Based on the same argument it was found that the 1976, 1977, and 1978 accident models were Poisson distributed. By utilizing these results it was found reasonable to predict the 1979 accident safety model as Poisson distributed too.

The validity of this model, as well as most accident models, for future predictions is based upon the assumption that no change in the safety program has been accomplished. If so the expected number of future accidents may be predicted. But in general this might not be true since the moment an accident occurs or after the investigation process of an accident have been completed some causes and problem areas become apparent and correction measures are established.

Those measures influence the model and future accident prediction becomes a problem. But at least this model can be used as an upper bound for future expected accidents since any corrections made will result in accident reduction.

Another problem area is that in general the model will not account for each type of accident but only for the total number. In such a case further analysis of the accident data might be necessary to determine the distribution of each type of accident. In cases where there is insufficient accident data, separate distributions for each type of accident might not be feasible. Statistical accuracy requires a large sample size. Similar accidents occurring on like equipment may not be frequent enough to yield accurate estimates of probability.

Another important factor that influences the development of an accident model is the complexity of the structure of the organization. That is companies or organizations with more homogeneous activities should be modeled much more easily than those with complex and different types of activities. Thus the need for studying and continuously analyzing the accident model is a must for complex organizations. By sub-modeling a complex organization, that is by dividing the organization into homogeneous subsets (such as same departments, occupations, etc.) each of which is easier to be modeled separately. Developing those individual models the safety efficiency of individual departments may be studied as well as the overall safety corporate efficiency.

Though the modeling aspect is in many cases complex and the findings are approximations based on the assumptions of certain probability distributions nevertheless close and continuous study of accident data reveal a lot of information which will help in prevention of accidents as well as estimation of the cost due to such accidents.

This safety performance field is an ever expanding area for future research and development.

TABLE II

Code I. Coding the days of the week

Code	Day
1	Sunday
2	Monday
3	Tuesday
4	Wednesday
5	Thursday
6	Friday
7	Saturday

TABLE III

Code II. Coding Occupations

<u>Code</u>	<u>Occupation</u>
01	Pipefitter
02	Driver
03	Laborer
04	Service station
05	Waitress
06	Machinist
07	EMD Supervisor
08	Open mess Employee
09	PW Grounds
10	Cook/waiter
11	Sales clerk
12	Model maker
13	Carpenter
14	Cashier
15	Gardener
16	Dishwasher
17	Painter
18	Mechanic
19	Fireman
20	Personnel off.
21	M.E. Technician
22	Chemist
23	Meterologist
24	NAVEX Storeman
25	Professor
26	Pestcontrollman
27	Ser. Sta. Attend.
28	Warehouseman
29	Plate maker
30	H.F. lab worker

<u>Code</u>	<u>Occupation</u>
31	Boilerman
32	Pantry person
33	Draftsman PW
34	Electronic Tech
35	Food Service Wk.
36	NAVOCEAN REP.
37	Security officer
38	Crane operator
39	Foreman Aero
40	Plumber
41	Computer Tech
42	Truck Driver
43	Manager
44	Pest Cntrlman
45	Maintenance worker
46	Cashier checker
47	General Helper
48	Ships mate
49	Shop planner
50	Bartender
51	Child care Attendant
52	Aero technician
53	Yoc
54	Janitor
55	Greenskeeper
56	Multilith op
57	Visual Display Art
58	Library Tech.
59	Voucher Examiner
60	Household Goods Inspector
61	Messenger

Table III (Continued)

<u>Code</u>	<u>Occupation</u>
62	MVO
63	Supply Supervisor
64	Barber
65	Boat technician
66	Claims examiner
67	Printer
68	Dock Mstr
69	Planner/Est.
70	Equip. Spec.
71	Acania First
72	Oceanographer

Table III (Continued)

TABLE IV

Code III. Coding Departments

<u>Code</u>	<u>Department</u>
01	Public Wks
02	Navel Exchange
03	Open Mess NAF
04	Mech Eng. Dept.
05	NPG Staff
06	NAF USN
07	Gardener
08	NPS Open Mess
09	EM Galley
10	NAVEX
11	Aero dept.
12	NAVEX
13	EPRF-Tech lib
14	NAF Golf course
15	NAF Bowling Lns
16	FNWC
17	Fire Dept
18	Civ Personnel
19	Physics Dept
20	Chaplain
21	Food Service
22	Aero
23	Admin NPS
24	Supply
25	Nat'l Marine Fis
26	Print Shop
27	Security
28	Boiler house

<u>Code</u>	<u>Department</u>
29	Open Mess
30	Comptroller
31	NPS
32	C.O.M.
33	MSSA/Staff
34	Oceanography
35	EM Galley
36	Recreation
37	Aero
38	Library
39	Av Safety
40	EE
41	EMD
42	Computer Center
43	DRMEC
44	MARDAC
45	RV Acania

Table IV (Continued)

YEAR	N Number of Samples	λ The Maxi- mum of D^+ , D^-	D^+ The Supremum of the Differences S-F (Sample-The- oretical Distribu- tions)	D^- The Supremum of the Differences es F-S	Z The Statistic used to obtain the Probabilities	The Probability of the Statistic Exce- eding Z if the Hypo- thesis of Equality is true and the Alte- rnative is one sided	The Probability of Exce- eding Z when the Hypo- thesis of Equality is true and the Alternati- ve Hypothesis is two sided.	REMARKS
1975	53	0.1460	0.0669	0.1460	1.0627	0.1045	0.2087	We accept the hypothesis that the Sample comes from Exp($\lambda=0.15$)
1976	62	0.1975	0.0830	0.1975	1.7683	0.0017	0.0033	We accept the hypothesis that the sample co- mes from Exp ($\lambda=0.22$)
1977	66	0.1730	0.0578	0.1730	1.4058	0.0192	0.0384	We accept the hypothesis that the sample co- mes from Exp ($\lambda=0.19$)
1978	70	0.1730	0.0962	0.1730	1.4478	0.0151	0.0302	We accept the hypothesis that the sample co- mes from Exp ($\lambda=0.19$)

These results were based on the K-S cr sample test for
the interarrival times of the accidents of each year.

APPENDIX A

BOOLEAN ALGEBRA BASICS

DEFINITIONS - SYMBOLS

Variables: In Boolean algebra are considered the objects, classes, or elements (symbols are letters A, B, X, etc.).

Universe: The entire collection or group of all the variables under consideration

" + " = Read as OR is used for the OR operation

" · " = Read as AND is used for the AND operation

" - " = Read as NOT (negation) is used for negation.

For example \bar{A} (Read A NOT) means the opposite of A that is if A had value 0, \bar{A} has the value 1 and vice-versa (Or true and not true instead of 1 and 0).

Null and All Elements (\emptyset and I): represents all the classes that do not and all the classes that do exist respectively.

SUMMARY OF BOOLEAN IDENTITIES

$$X + 0 = X (\emptyset \text{ is always } 0)$$

$$X + 1 = 1 (I \text{ is always } 1)$$

$$X + X = X$$

$$X + \bar{X} = 1$$

$$X \cdot 1 = X$$

$$X \cdot 0 = 0$$

$$X \cdot X = X$$

$$X \cdot \bar{X} = 0$$

$$X + Y = Y + X$$

$$\overline{\bar{X}} = X$$

$$X \cdot \bar{Y} + X \cdot Y = X$$

$$X \cdot Y = Y \cdot X$$

$$X + (Y + Z) = (X + Y) + Z$$

$$X(Y \cdot Z) = (X \cdot Y)Z$$

$$X(Y + Z) = X \cdot Y + X \cdot Z$$

$$X + X \cdot Y = X$$

$$X(X + Y) = X$$

$$X + Y \cdot Z = (X + Y)(X + Z)$$

$$X + \bar{X} \cdot Y = X + Y$$

$$\overline{X \cdot Y} = \bar{X} + \bar{Y}$$

$$\overline{X + Y} = \bar{X} \cdot \bar{Y}$$

COMPUTER OUTPUT

"ACCIDENT TABLES AND PLOTS"

TABLE FOR DAYS OF WEEK

DAYS	TOT-AC	TYPE-A	TYPE-B	TYPE-C	TL-DAY	PL-DAY
1	7	0	0	7	0	0
2	49	7	2	40	79	7
3	51	10	3	39	58	21
4	46	11	0	35	145	0
5	49	6	0	43	23	0
6	52	9	0	43	89	0
7	17	2	0	15	15	0

TABLE OF MONTHS

MONTHS	TOT-AC	TYPE-A	TYPE-B	TYPE-C	TL-DAY	PL-DAY
1	14	5	0	9	31	0
2	25	8	1	16	154	10
3	20	2	0	18	9	0
4	19	1	0	18	20	0
5	22	1	0	21	10	0
6	22	3	1	18	10	3
7	22	4	1	17	25	2
8	26	5	1	20	45	4
9	27	3	0	24	14	0
10	26	5	1	21	34	9
11	30	8	0	22	57	0
12	18	0	0	18	0	0

TABLE OF YEARS

YEAR	TOT-AC	TYPE-A	TYPE-B	TYPE-C	TL-DAY	PL-DAY
1	53	7	3	43	39	9
2	82	14	1	67	92	10
3	66	14	0	52	217	0
4	70	10	1	60	61	9

OCCUP	TOT-AC	TABLE TYPE-A	OF TYPE-B	OCCUPATION TYPE-C	TL-DAY	PL-DAY
1	19	7	2	11	63	15
2	1	0	0	1	0	0
3	26	1	1	24	6	4
4	2	1	0	1	2	0
5	8	2	0	0	24	0
6	2	1	0	1	3	0
7	1	0	0	1	0	0
8	2	1	0	1	16	0
9	1	0	0	1	10	0
10	5	1	0	4	10	0
11	43	9	0	34	38	0
12	4	0	0	4	0	0
13	6	1	0	5	14	0
14	3	0	0	3	0	0
15	10	2	1	7	95	0
16	1	0	0	1	0	0
17	4	0	1	3	0	0
18	9	2	0	7	3	0
19	2	0	0	2	0	0
20	1	0	0	1	0	0
21	4	0	0	4	0	0
22	1	0	0	1	0	0
23	1	0	0	1	0	0
24	3	0	0	3	0	0
25	5	0	0	5	0	0
26	0	0	0	0	0	0
27	1	0	0	1	0	0
28	7	1	0	6	5	0
29	1	1	0	0	6	0
30	0	0	0	0	0	0
31	3	1	0	2	4	0
32	0	0	0	0	0	0
33	1	0	0	1	0	0
34	9	0	0	9	0	0
35	10	4	0	6	37	0
36	1	0	0	1	0	0
37	9	0	0	9	0	0
38	7	2	0	5	3	0
39	2	0	0	2	0	0
40	3	0	0	3	0	0
41	2	0	0	2	0	0
42	1	1	0	0	2	0
43	4	0	0	4	0	0
44	1	0	0	1	0	0
45	9	0	0	9	0	0
46	2	0	0	2	0	0
47	1	0	0	1	0	0
48	1	0	0	1	0	0
49	0	0	0	0	0	0
50	1	0	0	1	0	0
51	2	0	0	2	0	0
52	1	0	0	1	0	0
53	0	0	0	0	0	0
54	2	0	0	2	0	0
55	1	1	0	0	1	0
56	1	0	0	1	0	0
57	1	0	0	1	0	0
58	6	1	0	5	3	0
59	1	0	0	1	0	0
60	1	0	0	1	0	0
61	1	1	0	0	7	0
62	2	2	0	0	9	0
63	1	0	0	1	0	0
64	1	0	0	1	0	0
65	1	0	0	0	10	0
66	1	0	0	1	0	0
67	2	0	0	2	0	0
68	1	0	0	1	0	0
69	1	1	0	0	38	0
70	1	0	0	1	0	0

$\frac{71}{72}$

$\frac{1}{2}$

$\frac{0}{0}$

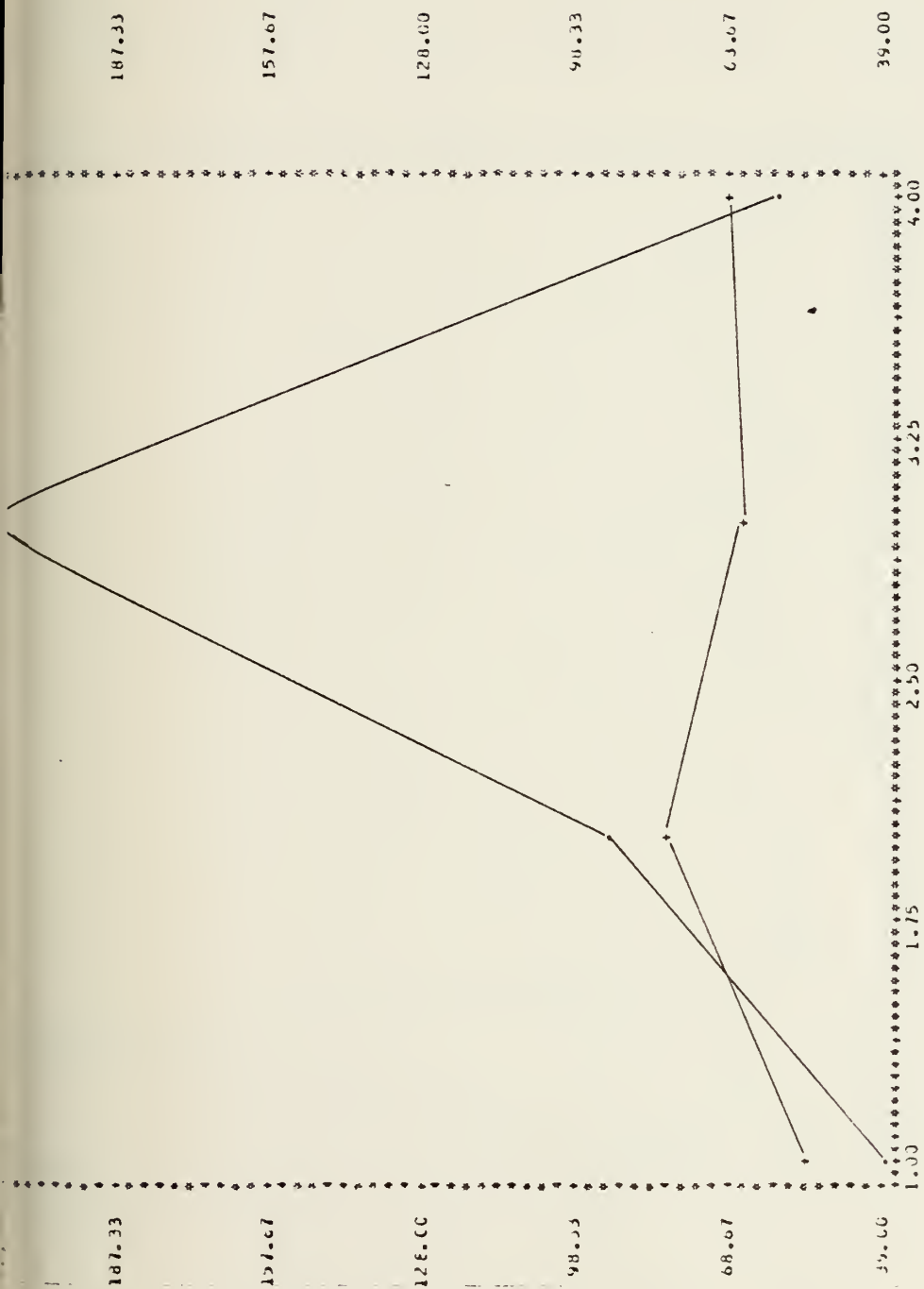
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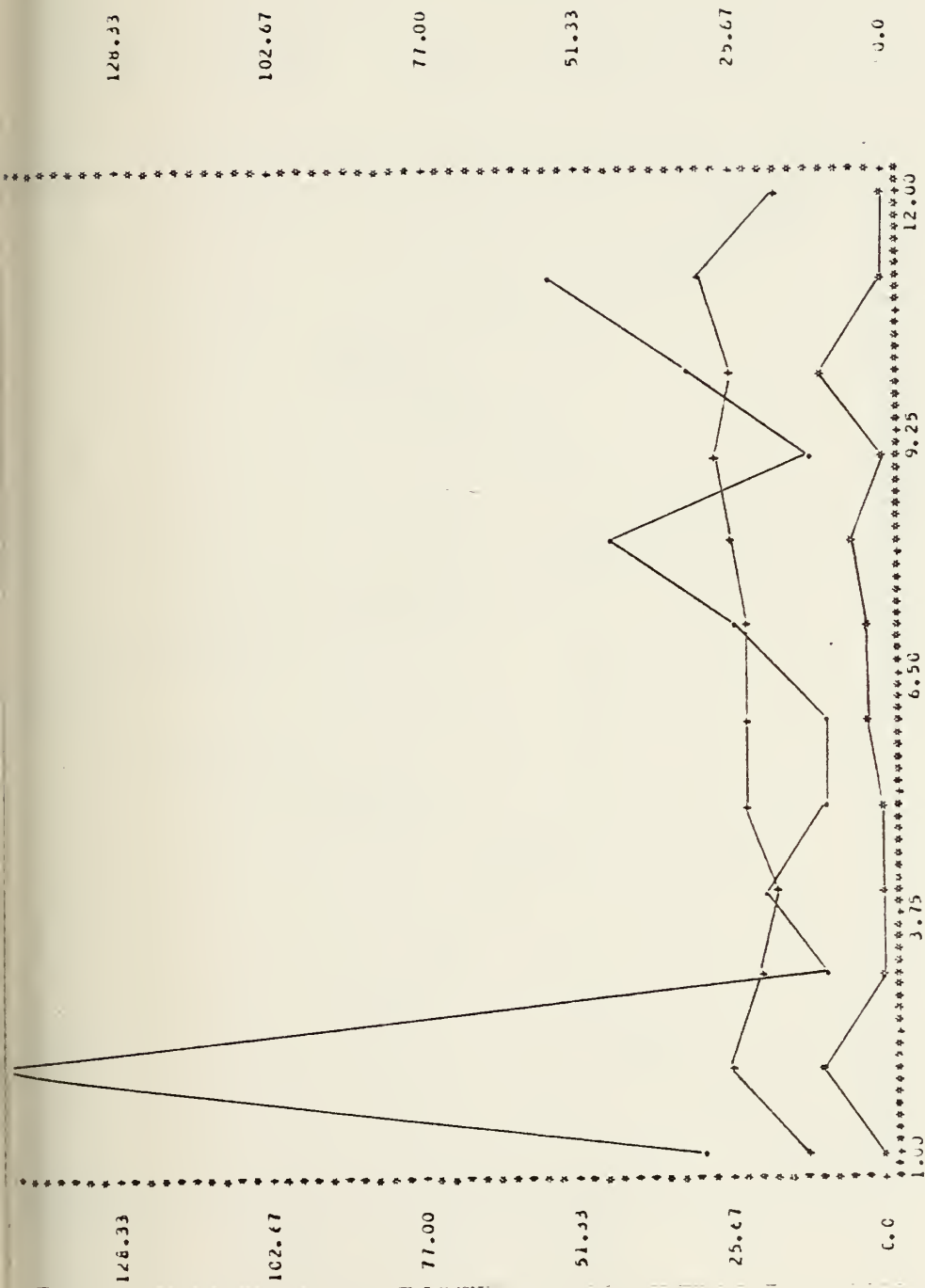
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DEPART	TOT-AC	TABLE TYPE-A	OF TYPE-B	DEPARTMENTS TYPE-C	TL-DAY	PL-DAY
1	90	15	5	71	219	28
2	53	14	0	39	56	0
3	3	0	0	3	0	0
4	3	1	0	2	3	0
5	2	0	0	2	0	0
6	1	0	0	1	0	0
7	1	0	0	1	0	0
8	1	1	0	0	16	0
9	1	0	0	1	0	0
10	0	0	0	0	0	0
11	1	0	0	1	0	0
12	2	0	0	2	0	0
13	1	0	0	1	0	0
14	1	0	0	1	0	0
15	1	0	0	1	0	0
16	7	1	0	6	8	0
17	2	0	0	2	0	0
18	1	0	0	1	0	0
19	7	0	0	7	0	0
20	0	0	0	0	0	0
21	1	0	0	1	0	0
22	4	0	0	4	0	0
23	2	1	0	1	7	0
24	10	0	0	10	0	0
25	1	0	0	1	0	0
26	1	1	0	0	6	0
27	7	0	0	7	0	0
28	1	0	0	1	0	0
29	1	1	0	0	23	0
30	1	0	0	1	0	0
31	2	0	0	2	0	0
32	21	7	0	14	47	0
33	1	0	0	1	0	0
34	6	0	0	6	0	0
35	0	0	0	0	0	0
36	8	2	0	6	21	0
37	4	0	0	4	0	0
38	9	1	0	8	3	0
39	2	0	0	2	0	0
40	3	0	0	3	0	0
41	4	0	0	4	0	0
42	1	0	0	1	0	0
43	1	0	0	1	0	0
44	1	0	0	1	0	0
45	1	0	0	1	0	0



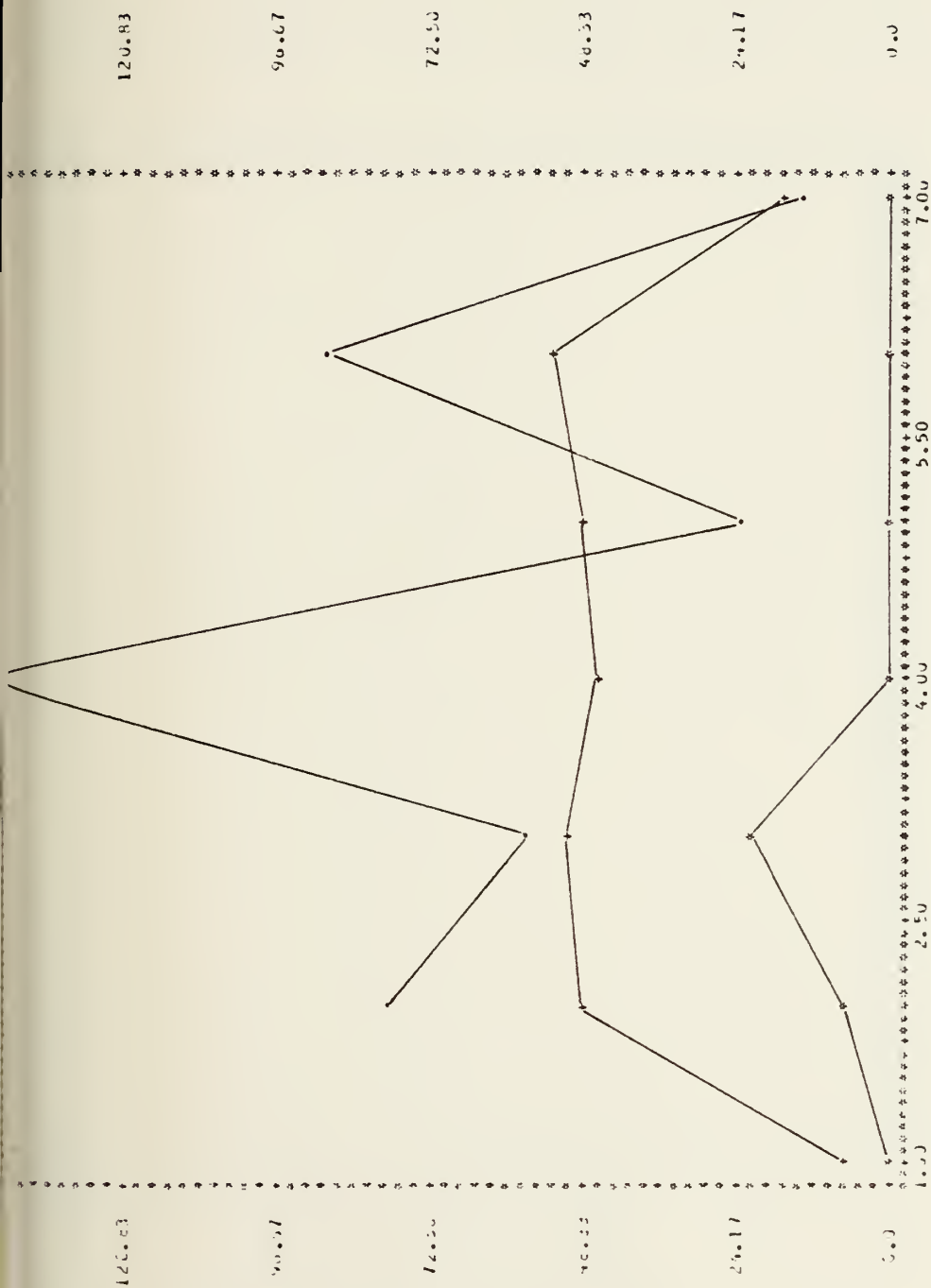
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YEARS VS. NUMBER OF ACCIDENTS (+)
 YEARS VS. NUMBER OF TOTAL DAYS OUT OF WORK (.)



X-SCALE: "M" = 0.137E 03 UNITS
 Y-SCALE: "U" = 0.257E 01 UNITS

MONTHS VS. NUMBER OF ACCIDENTS (+)
 MONTHS VS. TOTAL DAYS LOST (•)
 MONTHS VS. PARTIAL DAYS LOST (*)



WEEKS VS. NUMBER OF ACCIDENTS (+)

WEEKS VS. TOTAL DAYS LOST (-)

WEEKS VS. PARTIAL DAYS LOST (*)

79.17

63.23

47.50

31.67

15.83

G.C

79.17

63.53

47.50

31.67

15.83

0.0

1.00 16.75 36.50 56.25 72.00

A-SCALE: H=H= 0.087E 00 UNITS

Y-SCALE: H=H= 0.158E 01 UNITS

OCCUPATIONS VS. NUMBER OF ACCIDENTS (+)
OCCUPATIONS VS. NUMBER TOTAL DAYS LOST (.)
OCCUPATIONS VS. NUMBER PARTIAL DAYS LOST (*)

182.50

140.00

109.50

73.00

36.50

0.0

182.50

140.00

109.50

73.00

36.50

0.0

45.00

34.00

23.00

12.00

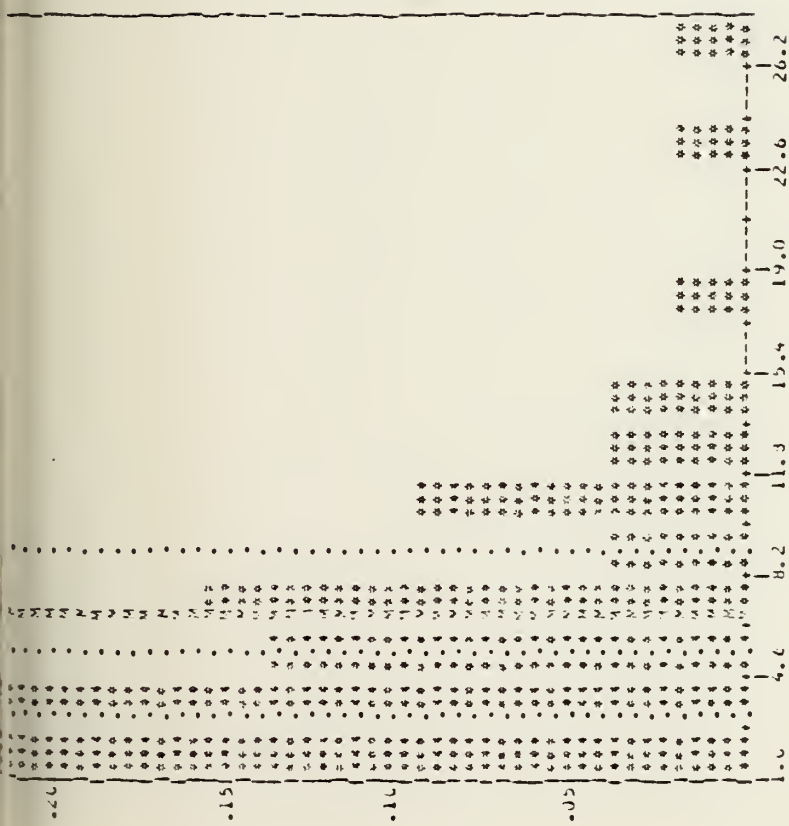
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X-SCALE: "X" = 0.550E 00 UNITS

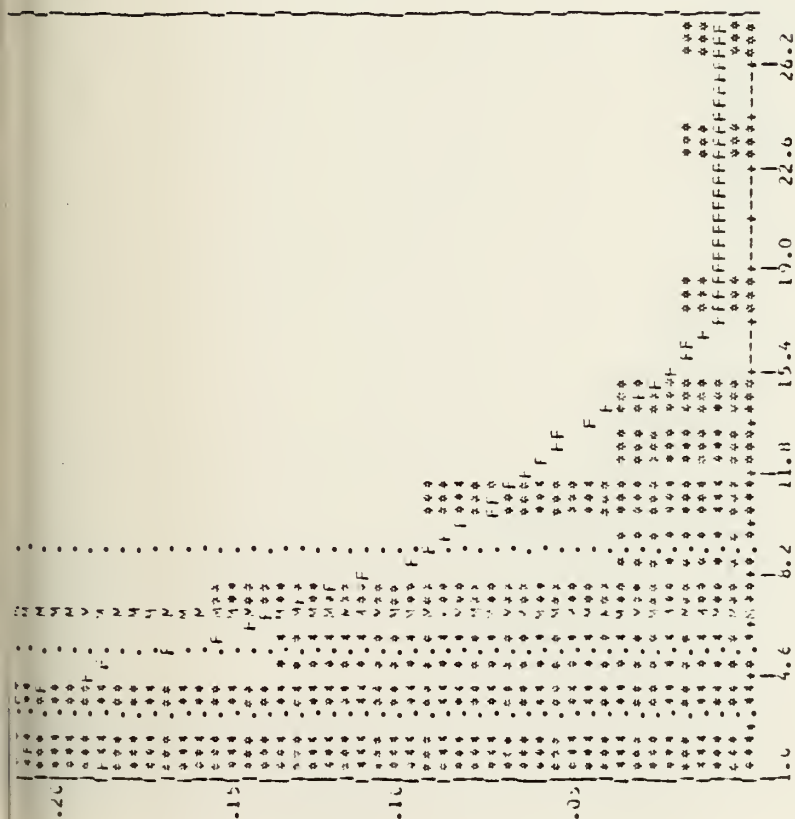
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DEPARTMENTS VS. NUMBER OF ACCIDENTS (+)
DEPARTMENTS VS. NUMBER OF TOTAL DAYS LOST (.)
DEPARTMENTS VS. NUMBER OF PARTIAL DAYS LOST (*)

COMPUTER OUTPUT
ACCIDENT HISTOGRAMS AND
K-S TESTS RESULTS

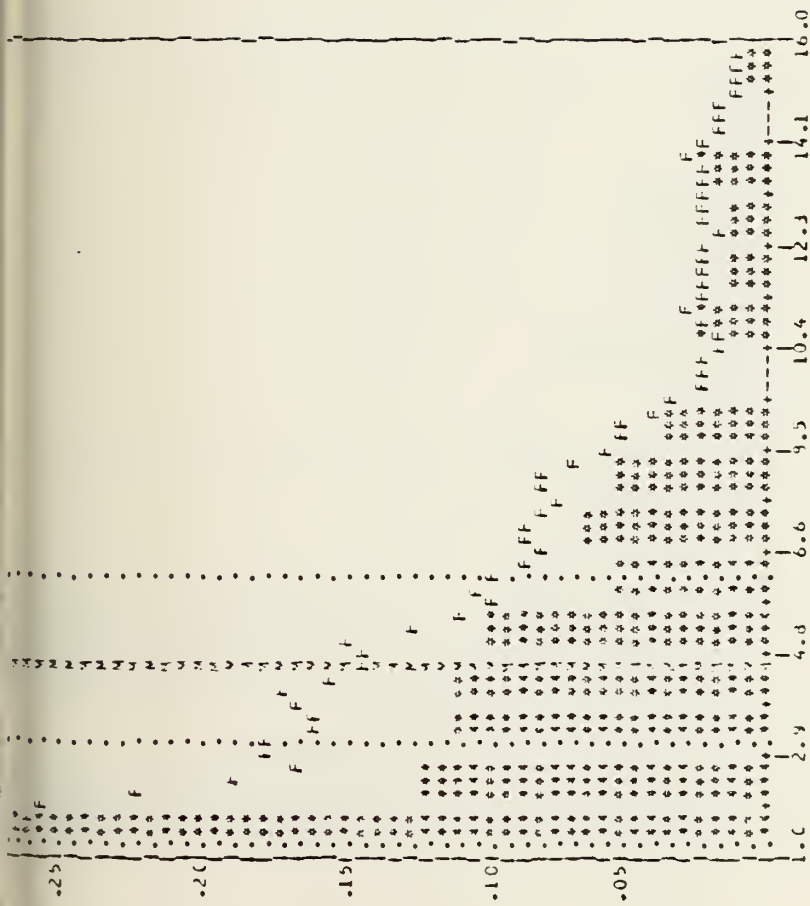


CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	5.471535E 00	VARIANCE	3.110311E 01	M3	3.167788E 02	MINIMUM	1.000000E 00
MEAN	5.471535E 00	STD DEV	5.576741E 00	M4	6.531490E 03	-10 QUANTILE	1.000000E 00
MEAN	5.471535E 00	CORR VAR	8.617132E-04	SKEWNESS	1.826472E 00	-25 QUANTILE	3.000000E 00
MEAN	5.471535E 00	MEAN DEV	3.386792E 00	KURTOSIS	3.804571E 00	-50 QUANTILE	5.000000E 00
MEAN	5.471535E 00	RANGE	2.700000E 01	BETA1	2.990735E 02	-75 QUANTILE	1.000000E 01
MEAN	5.471535E 00	MIDSPREAD	6.000000E 00	BETA2	6.151317E 03	MAXIMUM	2.000000E 01



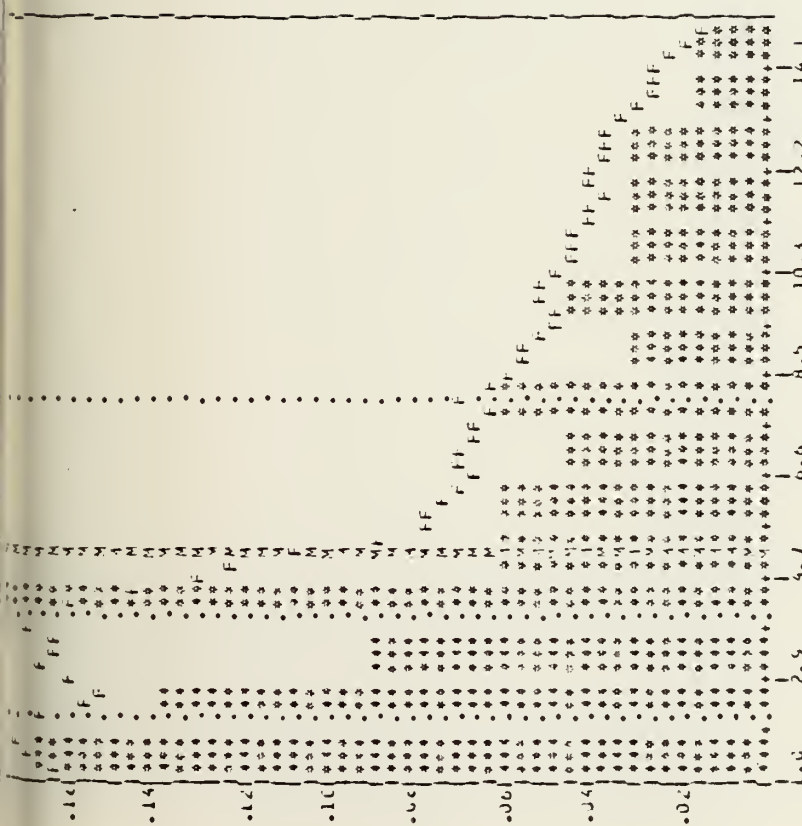
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MEAN	6.71093E 00	VARIANCE	3.11001E 01	M3	3.16776E 02	MINIMUM	1.00000E 00
STDEV	5.00000E 00	STD DEV	5.57674E 00	M4	6.58140E 03	.10 QUANTILE	1.00000E 00
COEFF VAR	5.00000E 00	COEFF VAR	8.61713E 01	SKENESS	1.82667E 00	.25 QUANTILE	3.00000E 00
MEAN DELV	5.00000E 00	MEAN DELV	3.30679E 00	DETOSSIS	1.50647E 00	.50 QUANTILE	5.00000E 00
RANGE	1.00000E 01	RANGE	2.70000E 01	DETA1	2.99071E 02	.75 QUANTILE	9.00000E 00
MIDSPREAD	6.00000E 00	MIDSPREAD	6.00000E 00	DETA2	6.15137E 03	.90 QUANTILE	1.50000E 01
MEAN	3.22161E 00					MAXIMUM	2.00000E 01

*** I M S (CURIST) *** WARNING I (IER = 33)



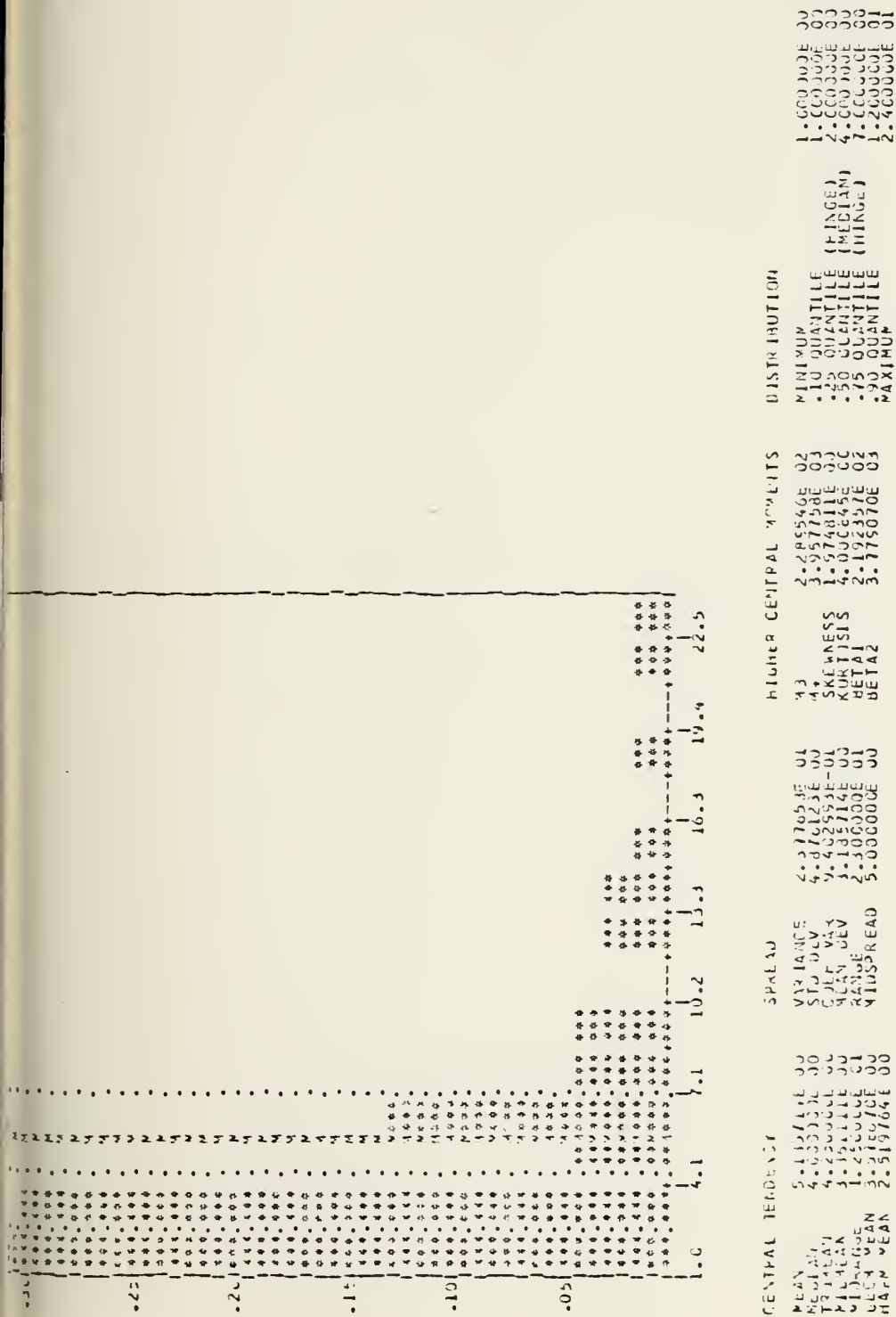
CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	4.32708E 00	VARIANCE	1.246555E 01	M3	5.97115E 01	MINIMUM	1.000000E 00
MEAN	3.60000E 00	STD DEV	3.58458E 00	M4	9.48927E 02	.10 QUANTILE	1.000000E 00
TRUNCAN	3.22000E 00	Coeff VAR	8.2917E-01	SKENESS	1.43167E 01	.20 QUANTILE	3.000000E 00
ALTERNATE	3.72451E 00	MEAN DEV	2.25122E 00	KURTOSIS	1.43167E 01	.30 QUANTILE	9.000000E 00
LEAST MEAN	3.36000E 00	RANGE	1.50000E 01	BETA1	5.35479E 01	.40 QUANTILE	1.000000E 00
H54 MEAN	2.100171E 00	MIOSPREAD	5.00000E 00	BETA2	6.67186E 02	MAXIMUM	1.000000E 01
0.2062	0.6142	0.2062	1.8676	0.0009	0.0019	0	

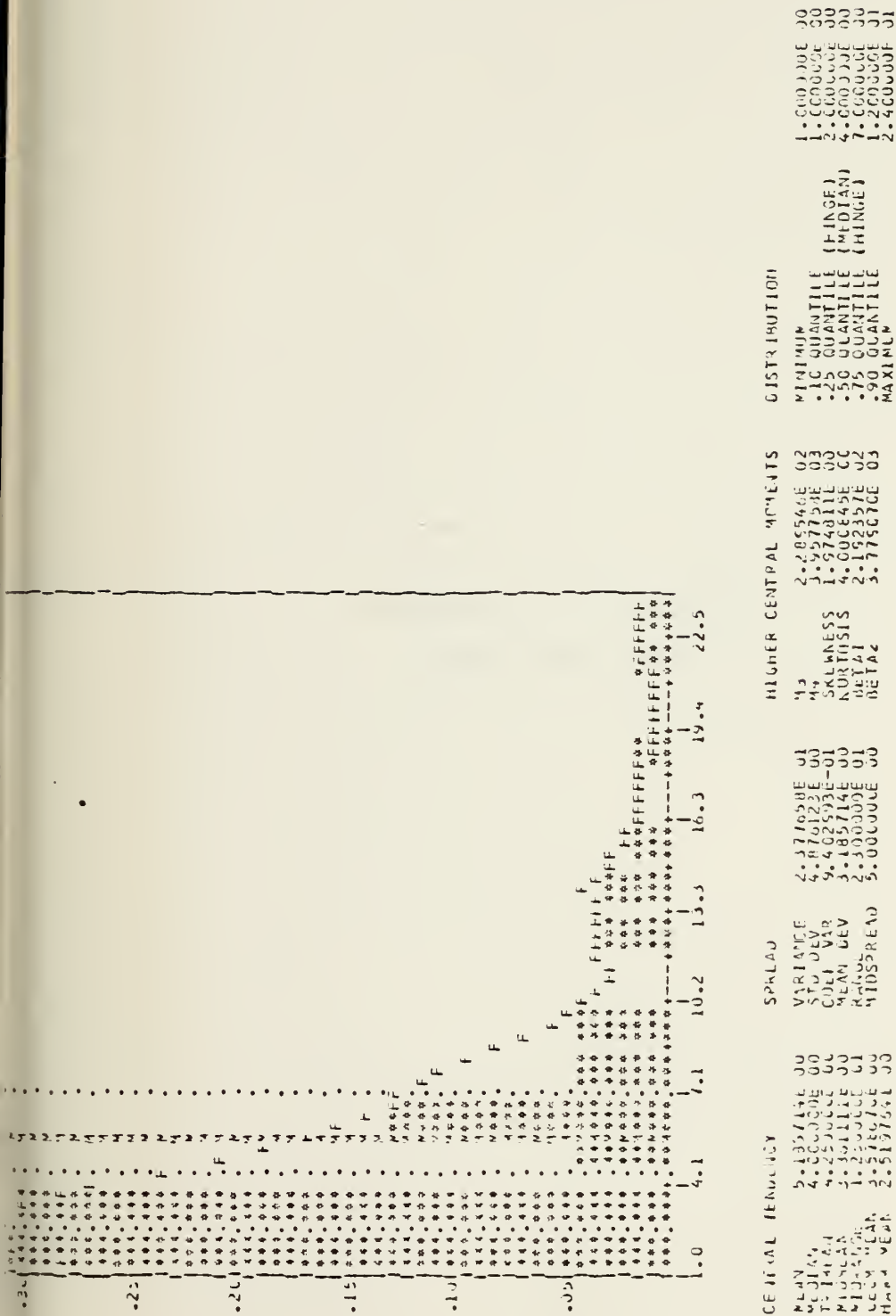
CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	5.160000E 00	VARIANCE	1.72917E 01	M2	4.82001E 01	MINIMUM	1.000000E 00
MEAN	7.000000E 00	STD DEV	3.76000E 00	M3	5.674875E 02	.10 QUANTILE	1.000000E 00
MEAN	4.320000E 00	Coeff VAR	7.31770E-01	M4	8.516343E-01	.25 QUANTILE	2.000000E 00
MEAN	8.000000E 00	MEAN DEV	2.87330E 00	KURTOSIS	-2.228713E-01	.50 QUANTILE	4.000000E 00
MEAN	3.330000E 00	RANGE	1.400000E 01	METAL	4.603159E 01	.75 QUANTILE	8.000000E 00
MEAN	2.44330E 00	PLUSPREAD	6.000000E 00	BETA2	5.512524E 02	.90 QUANTILE	1.100000E 01
						MAXIMUM	1.500000E 01



CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	5.18206E 00	VARIANCE	1.425407E 01	M3	4.820081E 01	MINIMUM	1.00000E 00
STDEV	4.00000E 00	STD DEV	3.740351E 00	M4	5.674875E 02	.10 QUANTILE	1.00000E 00
TRIMMED	4.33333E 00	Coeff VAR	7.317780E -01	KURTOSIS		(HINGE)	2.00000E 00
MIDRANGE	4.32522E 00	MEAN DEV	2.313391E 00	-2.228710E -01		(MEDIAN)	2.00000E 00
WILCOX	4.00000E 00	RAANGE	1.400000E 01	METAL		(HINGE)	2.00000E 00
CLCV MEAN	5.18206E 00	MAUSPREAD	6.000000E 00	5.512524E 02		.75 QUANTILE	1.00000E 01
HART MEAN	2.743282E 00					MAXIMUM	1.50000E 01

*** I M S L (LUTIST) *** WARNING 0.1160 0.0336 0.0108 1 (IER = 33)





PROGRAM "DS" TO PRODUCE
TABLES AND PLOTS


```

12      IF(I.GT.12) GO TO 13
        IMON(I,1)=I
13      IF(I.GT.45) GO TO 14
        IDEP(I,1)=I
14      IOCC(I,1)=I
2       CONTINUE
C
C   UPDATE TABLES FOR DAYS MONTHS YEARS OCCUPATIONS
C   DEPARTMENTS
10      READ(1,100,END=20) (IREC(I),I=1,9)
        IF(IREC(1).EQ.0) GO TO 10
100     FORMAT(9(I2,2X))
        DO 1 J=2,7
          IHELP=IREC(J+2)
          IF(J.GE.6) GO TO 30
          IF(J.EQ.3.AND.IREC(8).EQ.0) GO TO 1
          IF(J.EQ.4.AND.IREC(9).EQ.0) GO TO 1
          IF(J.EQ.5.AND.(IREC(8).NE.0.OR.IREC(9).NE.0)) GO TO 1
          IHELP=1
30      IDAY(IREC(4),J)=IDAY(IREC(4),J)+IHELP
          IMON(IREC(2),J)=IMON(IREC(2),J)+IHELP
          IYEA((IREC(1)-74),J)=IYEA((IREC(1)-74),J)+IHELP
          IOCC(IREC(5),J)=IOCC(IREC(5),J)+IHELP
          IDEP(IREC(6),J)=IDEP(IREC(6),J)+IHELP
1       CONTINUE
        GO TO 10
C
C   WRITE THE INJURIES FOR DAYS MONTHS YEARS OCCUPATIONS
C   DEPARTMENTS
20      WRITE(6,201)
201     FORMAT(1H1,2X,////,17X,'TABLE FOR DAYS OF WEEK',
1//)
        WRITE (6,300)FORM
300     FORMAT(4X,27A2)
        WRITE(6,200) ((IDAY(I,J),J=1,7),I=1,7)
        WRITE(6,301)

```



```

301  FORMAT(1H1,2X,////,17X,'  TABLE  OF  MONTHS  ',
1//)
      DO 16 I=1,3
      FORM(I)=MON(I)
16   CONTINUE
      WRITE(6,300) FORM
      WRITE(6,200) ((IMON(I,J),J=1,7),I=1,12)
      WRITE(6,401)
401  FORMAT(1H1,2X,////,17X,'  TABLE  OF  YEARS  ',//)
      DO 17 I=1,3
      FORM(I)=YE(I)
17   CONTINUE
      WRITE(6,300) FORM
      WRITE(6,200) ((IYEA(I,J),J=1,7),I=1,4)
      WRITE(6,501)
501  FORMAT(1H1,2X,////,17X,'  TABLE  OF  OCCUPATION',
1//)
      DO 18 I=1,3
      FORM(I)=OCCUP(I)
18   CONTINUE
      WRITE(6,300) FORM
      WRITE(6,200) ((IOCC(I,J),J=1,7),I=1,72)
      WRITE(6,601)
601  FORMAT(1H1,2X,////,17X,'  TABLE  OF  DEPARTIENTS'
1,//)
      DO 19 I=1,3
      FORM(I)=DEP(I)
19   CONTINUE
      WRITE(6,300) FORM
      WRITE(6,200) ((IDEP(I,J),J=1,7),I=1,45)
200  FORMAT(7X,I2,5X,I3,5X,I3,5X,I3,5X,I3,4X,I5,3X,I5)
C
C  PLOT NUMBER OF ACCIDENTS VS DAYS OF WEEK, YEARS, MONTHS,
C  OCCUPATIONS AND DEPARTEMENTS.
C
      DO 8 J=1,5

```



```

      GO TO (91,92,93,94,95),J
91    DO 3 I=1,4
      X(I)=I
      Y(I)=IYEA(I,2)
      Z(I)=IYEA(I,6)
      W(I)=IYEA(I,7)
3     CONTINUE
      N=4
      GO TO 99
92    DO 4 I=1,12
      X(I)=I
      Y(I)=IMON(I,2)
      Z(I)=IMON(I,6)
      W(I)=IMON(I,7)
4     CONTINUE
      N=12
      GO TO 99
93    DO 5 I=1,7
      X(I)=I
      Y(I)=IDAY(I,2)
      Z(I)=IDAY(I,6)
      W(I)=IDAY(I,7)
5     CONTINUE
      N=7
      GO TO 99
94    DO 6 I=1,72
      X(I)=I
      Y(I)=IOCC(I,2)
      Z(I)=IOCC(I,6)
      W(I)=IOCC(I,7)
6     CONTINUE
      N=72
      GO TO 99
95    DO 7 I=1,45
      X(I)=I
      Y(I)=IDEP(I,2)

```



```
      Z(I)=IDEP(I,6)
      W(I)=IDEP(I,7)
7      CONTINUE
      N=45
      WRITE(6,700)
700    FORMAT(1H1,///)
99     CALL PLOTP(X,Z,N,1)
      WRITE(6,700)
      CALL PLOTP(X,Y,N,2)
      WRITE(6,700)
      CALL PLOTP(X,W,N,3)
8      CONTINUE
      STOP
      END
```


PROGRAM "B" TO CALCULATE THE
INTERARRIVAL TIMES


```

C      PROGRAM TO CALCULATE THE INTERARRIVAL TIMES
C *****
C
C      ACCEPTS AS INPUT THE FILE FT01F001 AND
C      CALCULATES THE INTERARRIVAL TIMES OF THE
C      ACCIDENTS WHICH FILES INTO FILE FT02F001
C *****
C
C
C      DIMENSION TOT(100),DIF(100),IMTAB(12)
C
C      IMTAB(1)=DAYS OF MONTH I
DATA IMTAB/31,28,31,30,31,30,31,31,30,31,30,31/
IMET=0
40  IMET=IMET+1
    IC=0
C
C      READ IN THE DAYS OF OCCURANCE OF THE ACCIDENTS
20  READ(1,100) IY,IM,ID
    IF (IY.EQ.0) GO TO 30
C
C      CALCULATE THE CORRESPONDING JULIAN DAY
    IC=IC+1
    IM=IM-1
    IDAY=0
    IF (IM.EQ.0) GO TO 10
    DO 1 I=1,IM
      IDAY=IDAY+IMTAB(I)
1    CONTINUE
10   IDAY=IDAY+ID
    IF (IMET.EQ.2.AND.IM.GT.2) IDAY=IDAY+1
    TOT(IC)=IDAY
    GO TO 20
C
C      CALCULATE THE INTERARRIVAL TIMES
30  DIF(1)=TOT(1)

```



```

C
C   WRITES INTO FILE 2 INTERARRIVAL TIMES
    WRITE(2,200)
    WRITE (2,200) DIF(1)
    DO 2 I=2,IC
    DIF(I)=TOT(I)-TOT(I-1)
    WRITE(2,200) DIF(I)
200  FORMAT(F5.1)
2    CONTINUE
C
C   TAKE CARE OF LEAP YEAR
    IF (IMET.GE.4) GO TO 55
    GO TO 40
100  FORMAT(3(I2,2X))
55   STOP
    END

```


PROGRAM "C" TO PRODUCE HISTOGRAMS
AND PERFORM K-S TESTS


```

C*****
C* THIS PROGRAM ACCEPTS AS INPUTS THE INTERARRIVAL TIMES *
C* AND PRODUCE FOR EACH YEAR CORRESPONDING HISTOGRAMS:    *
C* EMPIRICAL PDF ; STATISTICS AND PERFORM K-S TEST GOODNESS*
C* OF FIT WITH EXPONENTIALS OF GIVEN LAMDA.                *
C*****
C
C
C
      DIMENSION X(100),VLAM(4),PDIF(6)
      EXTERNAL PDF
      COMMON /LAMDA/VL
C
C
C      GIVE LAMDA FOR EACH YEAR
      DATA VLAM / .1545, .23098, .19354, .1955/
      IMET=0
20    IMET=IMET+1
      VL=VLAM(IMET)
      IC=0
10    IC=IC+1
C
C      READ IN INTERARRIVAL TIMES
      READ(2,100) X(IC)
100   FORMAT(F5.1)
      IF(X(IC).NE.0.) GO TO 10
      IC=IC-1
C
C
C      USE OF LIBRARY SUBROUTINES TO PRODUCE HISTOGRAMS
C      AND PERFORM K-S GOODNESS OF FIT TESTS
      CALL HISTF(X,IC,0)
      CALL NKS1(PDF,X,IC,PDIF,IER)
      WRITE(6,200) (PDIF(I),I=1,6),IER
200   FORMAT(2X,6F8.4,I5)
      IF(IMET.LT.4) GO TO 20
      STOP
      END

```



```
C
C   SUBROUTINE REQUIRED BY THE NKS1 LIBRARY SUBROUTINE
C   TO CALCULATE THEORETICAL VALUE FOR EXPONENTIAL
SUBROUTINE PDF(X,Y)
COMMON /LAMDA/VL
Y=1.0-(EXP(-VL*X))
RETURN
END
```


COMPUTER FILE FT01F001

"DATA CODED"

FILE FTO1F001

OCCUPATIONAL INJURIES AND ILLNESSES DATA OF N.P.G.S.

THAT HAVE BEEN CODED UNDER FILE FTO1F001 AS FOLLOWS

A=YEAR, B=MONTH, C=DAY, D=DAY OF THE WEEK(1=SUNDAY, ETC.)

E=OCCUPATION(SEE OCCUPATION CODE) ,F=DEPARTMENT(SEE DEP CODE)

G=OSHA INJURY CODE(SEE OSHA CODE),H=TOTAL WORKDAYS LOST

I=PARTIAL WORKDAYS LOST

A	B	C	D	E	F	G	H	I
---	---	---	---	---	---	---	---	---

75	1	13	2	1	1	10	1	0
75	1	20	2	2	1	10	0	0
75	1	21	3	3	1	10	0	0
75	1	22	4	4	2	10	2	0
75	2	14	6	5	3	10	0	0
75	2	25	3	6	4	10	3	0
75	2	26	4	8	8	10	16	0
75	2	28	6	7	5	24	0	0
75	3	14	6	8	6	10	0	0
75	3	17	2	5	2	10	0	0
75	3	19	4	9	7	10	0	0
75	3	24	2	10	9	10	0	0
75	4	21	2	12	11	10	0	0
75	4	24	5	13	1	10	0	0
75	5	2	6	4	2	10	0	0
75	5	6	3	14	3	10	0	0
75	5	8	5	18	14	10	0	0
75	5	13	3	15	1	10	0	0
75	5	24	7	16	3	10	0	0
75	6	2	2	15	1	10	0	3
75	6	12	5	11	2	10	0	0
75	6	17	3	11	13	10	0	0
75	6	26	5	3	1	10	0	0
75	7	1	3	3	1	10	0	0
75	7	8	3	3	1	10	0	0

75	7	15	3	18	15	10	0	0
75	7	22	3	17	1	10	0	2
75	8	4	2	3	1	10	0	4
75	8	15	6	11	2	10	10	0
75	9	2	3	11	16	10	0	0
75	9	7	1	19	17	10	0	0
75	9	10	4	11	2	10	0	0
75	9	17	4	20	18	10	0	0
75	9	18	5	21	4	10	0	0
75	9	20	7	1	1	10	0	0
75	9	21	1	3	1	10	0	0
75	9	24	4	22	19	10	0	0
75	9	30	3	23	16	10	0	0
75	10	3	6	11	1	10	0	0
75	10	4	7	11	2	10	0	0
75	10	7	3	11	19	10	0	0
75	10	10	6	1	1	10	0	0
75	10	15	4	10	21	10	0	0
75	10	17	6	25	22	10	0	0
75	10	31	6	24	2	10	0	0
75	11	3	2	11	23	10	0	0
75	11	6	5	11	24	10	0	0
75	11	13	5	11	25	10	0	0
75	11	17	2	27	2	10	0	0
75	11	19	4	15	1	10	5	0
75	11	26	4	11	2	10	2	0
75	12	6	7	11	2	10	0	0
75	12	9	3	28	2	10	0	0
76	1	16	6	11	2	10	0	0
76	1	20	3	29	26	10	6	0
76	1	22	5	37	27	10	0	0
76	2	2	2	31	28	10	0	0
76	2	3	3	1	1	10	0	10
76	2	12	5	11	2	10	2	0
76	2	13	6	11	2	10	0	0

76	2	13	4	34	16	10	0	0
76	2	21	7	11	2	10	0	0
76	2	23	2	11	2	10	0	0
76	2	27	6	5	29	10	23	0
76	3	3	4	11	30	10	0	0
76	3	9	3	35	32	10	4	0
76	3	12	6	17	1	10	0	0
76	3	17	4	5	2	10	0	0
76	3	25	5	13	1	10	0	0
76	4	2	6	3	1	10	0	0
76	4	5	2	3	1	10	0	0
76	4	8	5	1	1	10	0	0
76	4	12	2	15	1	10	0	0
76	4	16	6	36	15	10	0	0
76	4	18	1	35	33	10	0	0
76	4	23	6	18	36	10	0	0
76	4	26	2	35	2	10	0	0
76	4	30	6	3	1	10	0	0
76	5	4	3	11	2	10	0	0
76	5	10	2	18	1	10	0	0
76	5	17	2	35	2	10	0	0
76	5	18	3	11	2	10	0	0
76	5	19	4	37	31	10	0	0
76	5	20	5	37	27	10	0	0
76	5	27	5	3	2	10	0	0
76	5	28	5	40	1	10	0	0
76	6	2	4	37	31	10	0	0
76	6	3	5	38	1	10	0	0
76	6	5	7	11	2	10	0	0
76	6	8	3	37	27	10	0	0
76	6	14	2	39	22	10	0	0
76	6	15	3	35	2	10	0	0
76	6	17	5	43	32	26	0	0
76	6	22	3	42	2	10	2	0
76	6	24	5	1	1	10	0	0
76	6	25	6	3	32	10	0	0

76	6	29	3	15	1	10	0	0
76	7	7	4	43	24	10	0	0
76	7	9	6	44	1	10	0	0
76	7	10	7	11	2	10	0	0
76	7	13	3	35	2	10	12	0
76	7	14	4	45	1	10	0	0
76	7	17	7	46	32	10	0	0
76	7	19	2	3	1	10	0	0
76	8	2	2	28	24	10	0	0
76	8	3	3	47	1	10	0	0
76	8	17	3	13	1	10	14	0
76	8	19	5	10	34	10	0	0
76	8	23	2	19	27	10	0	0
76	8	24	3	57	2	10	0	0
76	8	25	4	3	1	10	0	0
76	8	26	5	11	2	10	0	0
76	8	27	6	50	32	10	0	0
76	8	28	7	11	2	10	10	0
76	9	4	7	5	32	10	0	0
76	9	16	5	10	32	29	10	0
76	9	22	4	45	1	10	0	0
76	9	27	2	3	1	10	0	0
76	9	28	3	1	1	10	2	0
76	10	7	5	38	2	10	1	0
76	10	8	6	18	2	10	1	0
76	10	21	5	48	38	10	0	0
76	10	29	6	5	32	10	0	0
76	11	3	4	34	1	10	0	0
76	11	10	4	40	1	10	0	0
76	11	11	5	11	1	10	1	0
76	11	19	6	34	16	10	0	0
76	11	22	2	15	1	10	0	0
76	11	23	3	11	24	10	0	0
76	11	24	4	11	39	10	0	0
76	11	29	2	31	1	10	4	0
76	12	1	4	1	1	10	0	0

76	12	2	5	38	1	10	C	0
76	12	13	2	40	1	10	0	0
76	12	20	2	21	4	10	0	0
77	1	4	3	38	1	10	2	0
77	1	8	7	51	36	10	0	0
77	1	17	2	35	32	10	20	0
77	1	27	5	52	37	10	C	0
77	2	4	6	54	39	10	0	0
77	2	8	3	12	37	10	0	0
77	2	9	4	1	1	10	C	0
77	2	11	6	55	36	10	11	0
77	2	16	4	15	1	10	90	0
77	2	17	5	38	1	10	0	0
77	2	18	6	35	2	10	C	0
77	2	26	7	3	2	10	C	0
77	2	28	2	3	32	10	6	0
77	3	3	5	25	40	10	0	0
77	3	11	6	12	19	10	C	0
77	3	14	2	56	41	10	0	0
77	3	17	5	13	5	10	0	0
77	3	21	2	11	38	10	C	0
77	3	23	4	14	32	10	0	0
77	3	25	6	43	32	10	0	0
77	3	28	2	58	38	10	C	0
77	4	1	6	1	1	10	20	0
77	4	12	3	11	43	10	0	0
77	4	23	7	43	32	10	C	0
77	5	5	5	18	36	10	C	0
77	5	20	6	11	40	10	0	0
77	5	24	3	59	24	10	C	0
77	5	28	7	28	32	10	C	0
77	6	10	6	60	24	10	0	0
77	6	15	4	1	1	10	0	0
77	6	22	4	61	23	10	7	0
77	6	23	5	62	2	10	1	0

77	7	7	5	12	22	10	0	0
77	7	11	2	46	2	10	C	0
77	7	15	6	18	2	10	C	0
77	7	25	2	1	1	10	8	0
77	8	4	5	62	16	10	8	0
77	8	5	6	63	24	10	C	0
77	8	14	1	64	2	10	C	0
77	8	15	2	38	1	10	C	0
77	8	19	6	11	2	10	C	0
77	8	31	4	11	2	10	3	0
77	9	2	6	45	1	10	C	0
77	9	7	4	33	1	10	0	0
77	9	20	3	34	15	10	0	0
77	9	22	5	11	2	10	C	0
77	9	26	2	18	1	10	2	0
77	9	27	3	41	42	10	0	0
77	9	29	5	15	1	10	0	0
77	9	30	6	66	24	10	0	0
77	10	7	6	3	1	10	0	0
77	10	13	5	45	1	10	C	0
77	10	19	4	3	1	10	0	0
77	10	25	3	3	1	10	0	0
77	10	27	5	34	1	10	C	0
77	10	31	2	6	37	10	C	0
77	11	2	4	68	36	10	0	0
77	11	3	5	67	41	10	0	0
77	11	4	6	35	32	10	1	0
77	11	7	2	15	1	10	0	0
77	11	14	2	69	1	10	38	0
77	11	15	3	58	33	10	0	0
77	11	23	4	34	19	10	C	0
77	11	29	3	45	1	10	C	0
77	12	2	6	21	22	10	C	0
77	12	7	4	58	38	10	0	0
78	1	4	4	34	19	10	0	0

78	1	10	3	38	1	10	0	0
78	1	20	6	45	1	10	0	0
78	2	3	6	1	1	10	0	0
78	2	8	4	34	1	10	0	0
78	2	17	6	11	2	10	3	0
78	2	23	5	18	2	10	0	0
78	3	7	3	28	24	10	0	0
78	3	22	4	70	40	10	0	0
78	3	25	7	28	32	10	5	0
78	4	1	7	11	2	10	0	0
78	4	4	3	71	34	10	0	0
78	4	5	4	58	38	10	0	0
78	4	6	5	28	2	10	0	0
78	4	9	1	24	2	10	0	0
78	5	1	2	45	1	10	0	0
78	5	2	3	72	34	10	0	0
78	5	3	4	65	36	29	10	0
78	5	5	3	3	1	10	0	0
78	5	21	1	25	19	10	0	0
78	6	14	4	35	32	10	0	0
78	6	28	4	3	36	10	0	0
78	6	30	6	13	1	10	0	0
78	7	5	4	11	2	10	4	0
78	7	13	5	51	2	10	0	0
78	7	14	6	11	2	10	0	0
78	7	21	6	5	32	10	1	0
78	7	25	3	3	1	10	0	0
78	7	27	5	72	34	10	0	0
78	7	31	2	10	34	10	0	0
78	8	1	3	37	17	10	0	0
78	8	4	6	5	32	10	0	0
78	8	8	3	59	1	29	0	0
78	8	10	5	3	1	29	0	0
78	8	14	2	3	32	10	0	0
78	8	17	5	25	12	10	0	0
78	8	21	2	11	45	10	0	0

78	8	24	5	11	1	10	0	0
78	9	11	2	45	34	10	C	0
78	9	12	3	25	12	10	C	0
78	9	21	5	37	27	10	0	0
78	9	22	6	15	1	10	C	0
78	9	29	6	14	2	99	0	0
78	10	5	5	3	1	10	C	0
78	10	6	6	1	1	10	19	0
78	10	10	3	17	1	10	0	0
78	10	14	7	54	36	10	0	0
78	10	16	2	11	2	10	C	0
78	10	18	4	58	38	10	3	0
78	10	26	5	1	1	10	0	0
78	10	30	2	37	27	10	0	0
78	10	31	3	1	1	10	10	9
78	11	7	3	58	38	10	C	0
78	11	8	4	11	2	10	3	0
78	11	12	1	37	27	10	0	0
78	11	14	3	1	1	10	3	0
78	11	17	6	67	41	10	C	0
78	11	20	2	1	1	10	0	0
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78	11	30	5	13	1	10	C	0
78	12	4	2	45	32	10	C	0
78	12	5	3	17	1	10	0	0
78	12	6	4	11	38	10	0	0
78	12	11	2	1	1	10	C	0
78	12	13	4	3	1	10	0	0
78	12	15	6	24	41	10	0	0
78	12	16	6	41	44	10	0	0
78	12	18	2	21	19	10	C	0
78	12	21	4	34	37	10	C	0
78	12	29	5	31	1	10	0	0

COMPUTER FILE FT02F001

"INTERARRIVAL TIMES"

FILE FT02F001 'INTERARRIVAL ACCIDENT TIMES'

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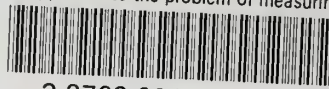
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